

VIEWING THE FUTURE IN THE PAST

Historical Ecology Applications
to Environmental Issues



EDITED BY

H. Thomas Foster II, Lisa M. Paciulli, and David J. Goldstein

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PREFACE

The essays in this book represent a wide range of authors, loci, and subjects. Yet they collectively demonstrate the value and necessity of looking at environmental problems as a long-term process that involves humans as a causal factor. It is increasingly apparent to environmental and earth scientists that humans have had a profound effect on the physical, climatological, and biological earth. Consequently, understanding any aspect of the earth within the past 10,000 years means understanding the density and activity of *Homo sapiens*. A study of the Holocene requires including humans as a causal factor. This realization has led many scientists to rename the Holocene the Anthropocene. Collectively, the authors provide evidence that ecosystems, economies, and landscapes must be understood through the study of historical data sets that span generations.

The authors in this book go beyond documenting human impacts on the environment. Many of them demonstrate how studying the past can inform our present and future. We argue for an applied archaeology where knowledge of the past is used to solve modern problems. Since current problems are the result of historical trajectories, human interactions, demographics, climate trends, and more, we must understand the past to solve today's problems. Archaeology and historical sciences offer advantages over some other sciences because archaeologists and historical ecologists can study the long-term effects of processes in the past. They can study the beginning and the end of a process because it occurred in the past. Such long-term, generational data sets are very expensive to collect for present times.

Many contributors to this collection first met at a conference, Field to Table, organized by David Goldstein and sponsored by the College of Arts and Sciences and the South Carolina Institute of Archaeology and Anthropology. The conference was envisioned by David Goldstein as a way to bring together diverse specialists who were researching issues dealing with subsistence and historical ecology.

Charles Cobb had the vision to build a visiting scholars conference at the South Carolina Institute of Archaeology and Anthropology. Thanks are owed also to Mary Anne Fitzpatrick, the dean of the College of Arts and Sciences at

the University of South Carolina; to Carole Crumley for her comments; and to the University of Tulsa for its grant of a research fellowship to Foster to help with the editing and writing of the manuscript. Lisa Paciulli worked magic on the manuscript getting it into a form that was publishable. We all owe her tremendous gratitude.

Thomas Foster

How Archaeology and the Historical Sciences Can Save the World

Starting around 100,000 years ago, a relatively young and new species of primates began expanding into new environments and increasingly using new technology. That species, *Homo sapiens*, dramatically increased in population, in geographic range, and in the effect that it had on its local environment over the past 10,000 to 20,000 years. A study of the environment, particularly during the Holocene, has to include a thorough study of humans because humans have had such an effect on all levels of ecosystems. Despite evidence that humans may have altered entire ecosystems and caused mass extinctions (Miller et al. 2005), scientists are just beginning to understand long-term human-environmental interaction in the past (Kennett and Winterhalder 2006; Newsom and Ruggiero 1998; Fritz 2000; Hammett 2000; Douglas et al. 2004; Heckenberger et al. 2003; Peres et al. 2003; Shaw 2003; Burchard 1998; Clark and Royall 1996; Foster and Zebryk 1993; Delcourt et al. 1986; Delcourt and Delcourt 1997, Delcourt 1987; Foster et al. 2004; Rue et al. 2002; Rue 1987). Nevertheless, understanding human effects on the environment is one of the most important challenges facing governments and policymakers today.

Kathy Willis and John Birks recently argued that many ecological processes occur over a long time period (Willis and Birks 2006: 1265) and that a thorough understanding of biodiversity requires an understanding of ecosystems over equally long time periods. Environmental conservationists studying invasive species, fire, climate variability, and natural fluctuations must include long-term data and humans as a causal variable. Because humans historically have had a “mosaic” and localized effect, we need detailed knowledge of human demographics and migration history and an understanding of human behavior. Some historical ecology researchers such as Carole Crumley, William Balée, and William Roseberry provide long-term perspectives that are necessary for understanding human-environmental interactions and ecosystem changes (Wolf 1982; Crumley 1994; Balée 1994, 1998; Roseberry 1989). Forest ecology also has shown that modern forests have to be understood as a product of their past. Forest

environments reflect migration of vegetation and climate change (Petit et al. 2008). We argue that archaeology and historical anthropology can provide long-term and anthropogenic perspectives that are important for conservation and environmental-management policies (Petit et al. 2008; Willis and Birks 2006).

Restoration and management of anthropogenic effects on the environment require understanding not only where humans lived but also what actions they took and for how long and how those actions interacted with the environment. Integrated studies of humans and ecosystems reveal complex patterns that take long time periods to develop and that may transform multiple ecosystem levels or regions. Those past coupled relationships have legacy effects on the present and on the future (Liu et al. 2007; Redman and Kinzig 2003; Jackson and Hobbs 2009).

Anthropogenic effects on global climate and local environments are among the largest challenges facing humans today. The United Nations Convention on Biological Diversity notes that understanding the effects of forest fires as either natural phenomena or as anthropogenic events is important for global environmental management, economic development, and the elucidation of climatic change (Anderson 1994; Burchard 1998; Kammen et al. 1994; Robock and Graf 1994; Schule 2001). Thus, it is imperative that current policymakers and environmental managers understand the mechanisms and processes of anthropogenic effects on the environment over long time periods.

Interactions between humans and their environments have become so widespread and profound that Holocene ecology is anthropogenic ecology. In other words, long-term anthropological data must be included in studies of biodiversity, landscape change, water, climate change, and so on. Therefore, in the remaining sections of this essay, we show how historical ecology and archaeological data are being used to generate an anthropologically informed understanding of modern ecosystems. We discuss how historical forestry data and archaeology are useful for creating chronosequences of human effects on the environment. We also demonstrate how such data can be combined with data of varying scales for modern environmental management using landscape metrics of change and for forest management in Madagascar.

CHRONOSEQUENCES OF BIODIVERSITY FROM WITNESS TREES

Since Holocene ecosystems represent long-term phenomena intermingled with human interactions, historical and archaeological data are central to the understanding of the current, as well as the future, state of our planet. Historical data from maps combined with archaeological data can be used to create chronosequences of the effects of human activities on various landscapes. Because of the systematic nature of archaeological data and the volume of research that

is conducted by federally mandated cultural resource management projects, we can create statistically significant samples of chronosequences over multiple physiographic regions. Here we describe research using witness-tree data combined with archaeological data that can be used to quantify the effects of specific Native American activities such as horticulture, burning, and hunting on forest composition in the southeastern United States.

Witness trees are boundary markers that were recorded in field notes and on maps by land surveyors when land was obtained by the state and federal government in the late eighteenth and the early nineteenth centuries. The surveyors marked land boundaries by noting the trees at the corners of plots of land and the four surrounding trees used to locate the corner tree. The species, and sometimes the sizes, of these trees were recorded as well. These land surveys were conducted in all states to varying degrees and usually covered the entire state. Since land boundaries typically were square and took in relatively small areas, the witness trees represent a systematic survey of the forest composition when the surveys were conducted. For example, in Alabama, townships were divided into squares that were six miles long on each side (1,553 ha). Townships were further divided into one-mile-square lots called sections. In western Georgia, the lots were similarly square though the smallest survey unit was about a half-mile on a side. In western Georgia, the forest composition surveys were conducted every half-mile in 1827, immediately after Native Americans were removed from the region. As one of the 13 original colonies, Georgia conducted its own survey. Alabama's survey was completed by the federal Public Land Survey System. These historic documents for Georgia and Alabama are archived at the Georgia Department of Archives in Atlanta, Georgia, the Alabama Department of Archives in Montgomery, Alabama, and the Bureau of Land Management in Springfield, Virginia.

Researchers using witness-tree data have identified biases in the data. The land-survey maps show variability on a regional level because of minor variations in surveyors' techniques; however, all surveys contain tree species. It appears that some surveyors may have selected larger, longer-lasting trees as boundary markers. On rare occasions, such as during the Yazoo Land Fraud, there were intentional biases toward more economically profitable trees, beneficial surveys, and better land quality. These biases are well known and can usually be controlled (Black et al. 2002; Bourdo 1956). In spite of these problems, it is generally agreed that "witness tree data are the largest, most systematic, and most accurate form of data available for the pre-European settlement forests" (Bourdo 1956; Foster et al. 2004; Whitney 1994). Moreover, Black and colleagues (2002) state, "There are no known biases in the study area other than a tendency against a particular species of oak by one surveyor identified by our own research."

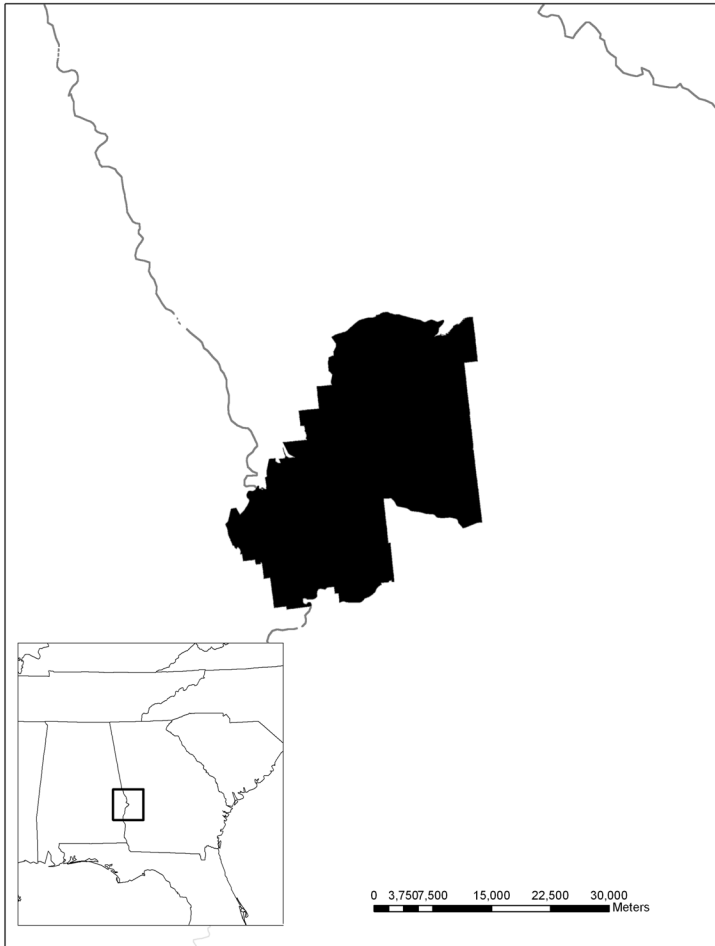


FIGURE 1. *Location of Fort Benning Army Base, Georgia and Alabama, United States of America*

In the current research project, the study area is west-central Georgia and central Alabama (Figure 1). This area covers three physiographic zones—the ridge and valley, the piedmont, and the coastal plain. The climate has hot, humid summers and mild winters. The warmest months are July and August, with average daily temperatures between 37° and 15° C. The coldest months are January and February, with average temperatures between 15° and 1° C. Annual precipitation is 105 cm. Soils consist of alluvial deposits from the piedmont and sands on the coastal plain. Historical forest species included longleaf pine (*Pinus palustris*), loblolly pine (*P. taeda*), and slash pine (*P. elliottii*) (Black et al. 2002).

Tree data were extracted from historic land-survey maps and digitized into a geographic information system (GIS; ArcGIS 9.3) as individual points for each tree. The total area includes 52,581 trees that were digitized, covering an area of approximately 20,000 km² (7,500 miles²). Then we defined catchments around Native American settlement areas. The catchments were defined as areas of impact by Native American subsistence activities. Native American settlements were dated through radiocarbon and seriation of artifacts. Population of each town was estimated by historic censuses and archaeological investigation. After dating the site's occupation, we then measured the length of time that the site was occupied and the length of time that the site had been abandoned as a measure of succession. We used the catchments as samples of the forest and then measured biodiversity using Shannon-Weiner's statistic.

Our research on the relationship between biodiversity and Native American settlements indicates that biodiversity and years of succession are highly negatively correlated. Biodiversity increases significantly as the amount of time since abandonment decreases. Or, the more time that has elapsed since abandonment, the less biodiversity. This finding is statistically significant ($p = .012$). At first, these results may seem somewhat counterintuitive, particularly to researchers of tropical forests. However, when the data are compared to those in other studies in the Southeast, there is a reasonable explanation. In earlier studies of anthropogenic effects on forest diversity, Foster and colleagues (Black et al. 2002; Foster et al. 2004) found that the density of some tree species near villages was higher, while the density of other tree species was lower. In the southeastern United States, pine dominates much of the forest. Native Americans increased biodiversity near villages by reducing pine and encouraging fruit, nut-producing, and fire-tolerant species. Correspondingly, they increased tree biodiversity beyond what would have existed without human activity. After humans stop increasing biodiversity of tree species, the forest composition gradually goes back to its nonhuman altered state. Next, we will show how these historical and archaeological data are being used for modern environmental management.

MODERN ENVIRONMENTAL MANAGEMENT

The United States Department of Defense (DoD) has a proactive approach to land management and environmental monitoring. The DoD is responsible for managing federally owned lands used for military training according to terms of the National Environmental Policy Act (NEPA) of 1969. Military training can impact air, soil, and water quality as well as the flora and fauna in the area. Consequently, the DoD must balance its training missions with environmental management. We have used archaeological and historical data about land use to

create metrics of change over time that can be used in a proactive way to plan and manage resources.

Landscape patterns are important indicators of human land-use impacts on the earth and are part of long-term analyses of ecological change. The immediate goal of this research was to identify and map trends in land-cover changes that have occurred since European settlement in the study region, to quantify where humans were and what activities impacted the landscape, and to develop techniques to measure those trends. Foster and colleagues (Foster et al. 2010; Foster et al. 2009) derived landscape measurements (metrics) that accurately characterized forest composition and land use at Fort Benning Military Reservation, Georgia. Then they used a variety of data sources to apply those metrics.

Fort Benning is situated along the fall line that borders the Appalachian Piedmont and the Gulf Coastal Plain in central Georgia and Alabama (Figure 1). The installation boundary is 73,837 ha in size and is near Columbus, Georgia. It lies partly within Muscogee, Chattahoochee, and Marion Counties in Georgia and partly in Russell County in Alabama.

Foster and colleagues (2009) focused on broad-scale indicators of landscape change, such as forest composition and fire frequency, that could be used by land managers for monitoring. A more complete description of the methods and results is published elsewhere (Olsen et al. 2007), so here we provide only a summary. Witness-tree data were used to characterize forest composition before Europeans cut down the forest in the study region. The witness-tree data were digitized into a geographic information system to create a digital model of forest composition when Native Americans occupied the area before 1827. Then, archaeological data were combined with these historic documents to evaluate human population density and economic activities that may have altered the landscape.

The archaeological data were collected from systematic sampling of the study area every 30 meters and excavating test units to identify buried cultural deposits (Elliott et al. 1995). Next, the historic data were compared to satellite imagery from 1974, 1983, 1986, 1991, and 1999 (Olsen et al. 2007). Although the data from the witness trees were coarser than those from satellite imagery and archaeological data, they still were useful.

The time series of landscape change shows persistent landscape variables as well as changes over time. Areas of bare ground have been relatively stable, whereas the location of deciduous forests has changed. There has been a trend in recent decades toward more pine forest, which is likely the result of forest management at Fort Benning for habitats that are essential for endangered species such as the red-cockaded woodpecker (*Picoides borealis*). The results from this study are currently being used by the monitoring coordinator at Fort

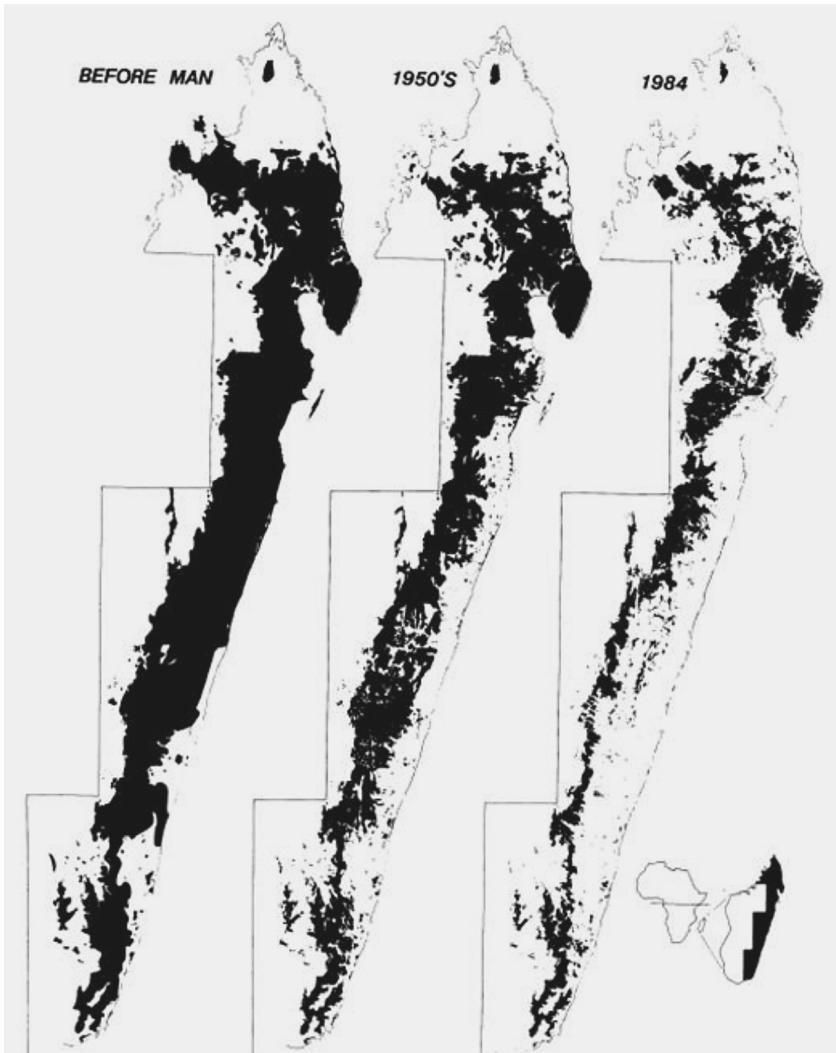


FIGURE 2. The image on the left depicts the estimated original extent, the image in the center is forest extent in the 1950s, and the image on the right shows forest cover in 1984. Sussman, Robert, Green, Glen, and Sussman, Linda, "Satellite imagery, human ecology, anthropology, and deforestation in Madagascar" *Human Ecology* 22 (1994):336. With kind permission from Springer Science and Business Media

Benning Military Reservation for choosing sampling variables for monitoring forest health.

MADAGASCAR FORESTS

Our final example of how long-term data could be used to positively affect environmental management and policy comes from Madagascar. Fauna began arriving on the island country via transoceanic dispersal-rafting events approximately 60 to 50 million years ago (Darlington 1957; Poux et al. 2005; Vences 2004). Madagascar's unique wildlife then evolved independent of human intervention (Tattersall 1982) until humans arrived approximately 2,000 years ago (Schüle 1990). The island is considered one of the "hottest biodiversity hotspots" in the world and a top global conservation priority (Goodman and Benstead 2003; Myers et al. 2000). Using long-term data from aerial photographs, vegetation maps (Humbert and Cours-Darne 1965), and satellite imagery, Green and Sussman (1990) showed the progression of deforestation on Madagascar over a 2,000-year period. Then, in order to elucidate the causes of the deforestation, Sussman et al. (1994) examined population trends, topography, ethnographic research, and satellite imagery over a 35-year period. They found that population increases, poverty, and slash-and-burn agriculture accounted for most of the rainforest loss in low elevation areas (Figure 2). They also identified deforestation "hotspots" as well as various problems for conservation and development. Moreover, Sussman et al. (1994) explained how conservation policies were not adequately addressing conservation issues.

The Malagasy government has employed integrated conservation and development projects (Wright 1992), community-based forest management programs (Kremen et al. 1999), nongovernmental organizations (Hannah et al. 1998), and other programs to try to protect its unique biodiversity, with varying degrees of success (Gezon 1997; Marcus 2001; Raik and Decker 2007). Although Sussman et al. (1994) presented long-term quantitative data and offered clear conservation recommendations, it appears that science is not playing as large a role as it could in Madagascar's conservation policies.

Sussman et al.'s (1994) work serves as a cautionary tale, forewarning that there may be fewer than 35 years (and now fewer than 15 years) to save the lowland rainforests of Madagascar's east coast. They recommend that long-term data from satellite imagery and ethnographic research be used to inform conservation management decisions and to evaluate the success or failure of conservation policies and development efforts before the eastern forests are gone.

These few examples are not isolated, nor are they applicable only to biodiversity. Anthropological data are useful for many types of environmental management and policy. Anthropologists such as Fekri Hassan and Vernon

Scarborough are using knowledge about ancient water management to support modern water management by the United Nations (Hassan 2010). Clark Erickson applied knowledge about ancient agriculture to help modern Peruvian farmers use methods that were more sustainable (Erickson 1998, 2002). William Rathje and his colleagues have analyzed modern trash dumps and recycling centers and have helped municipalities redesign more sustainable and effective landfills (Rathje and Murphey 2001). These types of applied historical ecology have tremendous potential for environmental management.

For anthropological and historical data to be useful for environmental management, the data have to capture critical information in measurable, units while not being too detailed. We believe that anthropological information also should meet the following criteria: it should be easy to measure, sensitive to stresses on the system, responsive to stresses in predictable manners, anticipatory and predictive of changes that can be averted by management actions, integrative, responsive to natural and anthropogenic disturbances and changes over time, and of known variability in response (Dale et al. 2002; Dale et al. 2004). Our research and applied anthropology indicate that data from a wide range of sources and scales can be combined successfully to create landscape metrics of change that are useful for managers and policymakers.

These types of data already are being collected on massive scales, thanks to federally funded cultural and natural-resource-management programs and projects. Cultural resource management alone is a billion-dollar industry in the United States (Altschul 2010) and is conducted in many other countries as well. Natural-resource-management funding would exceed that amount. Natural-resource-management plans and policies need to incorporate these long-term data and records of human activity on the landscape.

Human effects on the environment and on resource management are some of the most significant challenges facing global societies and governments today. The human population has doubled in the past 40 years and is expected to exceed 9 billion people by 2050. Consequently, our need to manage resources and control the anthropogenic effects on them is paramount. Since our understanding of biodiversity and ecosystems is based on historical data, input from archaeology and historical science is crucial to meeting these demands.

This type of applied historical ecology or applied archaeology is becoming more common in a wide range of applications. "Activist archaeology" has been applied to tourism, preservation, economic development, water management, race relations, and heritage management, as well as environmental management (Sabloff 2008; Little 2002; Stottman 2011). The essays in this book continue that recent trend as applied to modern ecosystems.

The essays offer an academic and transdisciplinary perspective on how human-resource use plays out in regional ecosystems and marks landscape change.

Many of these studies are developing ideas about how resource use in the past and its artifacts play a role in how we think about contemporary economic and cultural resources. In other essays, authors present multidisciplinary tools for producing baseline data that establish holistic methods for reconstructing resource development. Ultimately, these scenarios can affect how decisions are made today when we plan, design, deploy, and enact resource-management activities, given present and future available subsistence resources. All of these projects include a marked concern that humans be considered as ecological community members like any other organism. Since humans get what they need from their surrounding environments, we need to anticipate the consequences of mounting ecological pressures on ourselves, the other organisms in our communities, and the nonliving ecosystem components that we share.

As we strive to anticipate the future and to better understand the current ecological state of affairs as community members, this volume cues the past as a way to think about fruitful future strategies. It is exactly this quality that grants us an exceptional role in our ecological communities. Thinking sustainably forces us to consider the present state of resources to plan effectively for the future. Historical ecology lets us evaluate how we arrived at the present by cataloging and recounting the cumulative effects of human activity at the regional level so that our projections are historically contingent both ecologically and culturally.

We, as individuals, researchers and citizens, are at a unique crossroads where the results of our investigations give us the ability to forecast and understand the ecological and social variables that govern our contemporary politics. The approaches to these intersections between results and planning, however, are as diverse as the data and the researchers that created them. The research presented here demonstrates diverse holistic approaches to recording human and environment interactions. All the studies, in one way or another, engage a world beyond disciplinary and academic lines at the regional or local scale. All demonstrate human expressions of resilience in instances in light of changing resource bases. All document aspects of the innovations that humans have used or continue to employ across time and space either through technological change or through cultural or social behavior. Collectively, the essays demonstrate the diverse archaeological and historical record of long-term legacies or concerted efforts to manipulate resources in light of variable ecological and historical circumstance. Examples range from mobilizations of labor to changes in management strategies, from the construction of canals and causeways to the development flexible hunting/fishing/farming technologies or the enhancement of persistent and diverse organisms for subsistence.

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Diversity, Standardization, and the State

The Politics of Maize Agriculture in Postclassic Central Mexico

Documenting standardization is part of the backbone of the archaeological study of political economy. Archaeologists consider the standardization of material culture as one of the hallmarks of specialization (for example, Blackman et al. 1993; Brumfiel and Earle 1987; Clark and Parry 1990; Costin 1991; Rice 1981). Many of the goods that specialists produce are themselves commodities that circulate via local and extralocal spheres of exchange, such as markets or tributary networks, or via the integration of several different spheres (Calnek 1978; Brumfiel 1980). From a production standpoint, standardization suggests the development of economies of scale as specialists mass-produced goods to meet both demands and desires. From a consumption standpoint, it may suggest equitable access to market goods, the specialized production or consumption of prestige items, or simply mass tribute (Brumfiel 1987; Garratty 2009; Hicks 1991; Hirth 1998; Inomata 2001).

The archaeological study of agricultural intensification offers a unique vantage point from which to elucidate processes of standardization and diversity. On one hand, when defined in terms of the marginal utility of labor, intensification of agriculture suggests an increasing economic shift toward specialization in food production (Boserup 1965; Brookfield 1972; Geertz 1963). Intensification is not the exclusive product of demography, however, but is also related to the production of surpluses (1) to finance emerging political institutions via taxes or tribute, (2) to participate in direct or indirect ways with extralocal systems of exchange, such as markets; and (3) to contribute to and invest in the social relationships that constitute local communities (for example, Brookfield 1984, 1986; D'Altroy and Earle 1985; Erickson 2006; Morrison 1994; Sahlins 1972; Wolf 1966).

On the other hand, the sustainability and resilience of agriculture are often tied to how such systems maintain diversity. From an ecological perspective, some agricultural systems, such as swidden, are seen as fragile and stable only as long as the agricultural regime mimics an underlying natural order (for example, Geertz 1963). From an economic perspective, the persistence of agriculturalists

and smallholders is related to the ways in which they diversify their productive strategies across time and space (Netting 1993; Redman 1999: 95; Zimmerer 1993). The diversification of smallholder strategies includes specific land-use technologies, as well as the cultivation of crops. For Netting and Stone (1996), diversification constitutes a strategy by which smallholders maintain their independence in the face of broader economic and ecological systems and thus remain smallholders: “Reducing the diversity of enterprises means that there will inevitably be fewer variations in farming systems . . . and less household autonomy” (Netting and Stone 1996: 54, emphasis added).

When studying Netting’s work, it is important to keep in mind that most of the cases he studies exclusively show smallholders at work, maintaining diversity and maintaining autonomy. In many cases, however, the theme of the property-owning smallholder avoiding the tragedy of the commons via the responsible management of land offers only partial insight into the relationships between farmers and the state. Despite Netting’s position on the independence of smallholders and his characteristic de-emphasis of power and inequality (see Guyer 1997), agriculturalists do not exist in political economic vacuums. They must produce enough to maintain their families and farms while also producing a surplus to support their own social investments and to pay taxes, tithes, or tribute.

Eric Wolf’s view of peasants is somewhat similar to Netting’s but with an added twist: “The peasant retains—in his control of land and his capacity to raise crops on it—both his autonomy and his capacity to survive” (Wolf 1966: 17). The nuance is in the process. For Netting, smallholders are smallholders not just because they are property owners. Otherwise, absentee landlords would qualify, too. Instead, they are smallholders because the result of their in-depth agro-ecological knowledge is manifest as sustainability and perseverance. Wolf offers a much simpler and, indeed, more historically versatile perspective. Peasants develop strategies to survive. To retain the capacity to use land, they may rely on some strategies that are completely contrary to the expectations of ecologically minded scholars seeking to enshrine “traditional” practices as universally and transhistorically sustainable. This does not mean that all local farmers are inches from the margin, forever risking ruin (see, for example, Scott 1976). But one of the economic strategies that Netting misses is the capacity to adapt in ways that might be ecologically disruptive in the long term. Indeed, in order to maintain a degree of economic and social autonomy in the face of political pressure, agriculturalists often must increase production, standardize their practices, and reduce diversity.

In this essay I present a paleoethnobotanical approach to examining how agricultural diversity reflects changing relationships between farmers and political economic institutions. I examine this topic by focusing on maize agriculture and

political development at the Postclassic kingdom of Xaltocan in central Mexico. By analyzing maize morphology, I explore how the variability of maize present in the community changed through time as the polity developed and declined in political power.

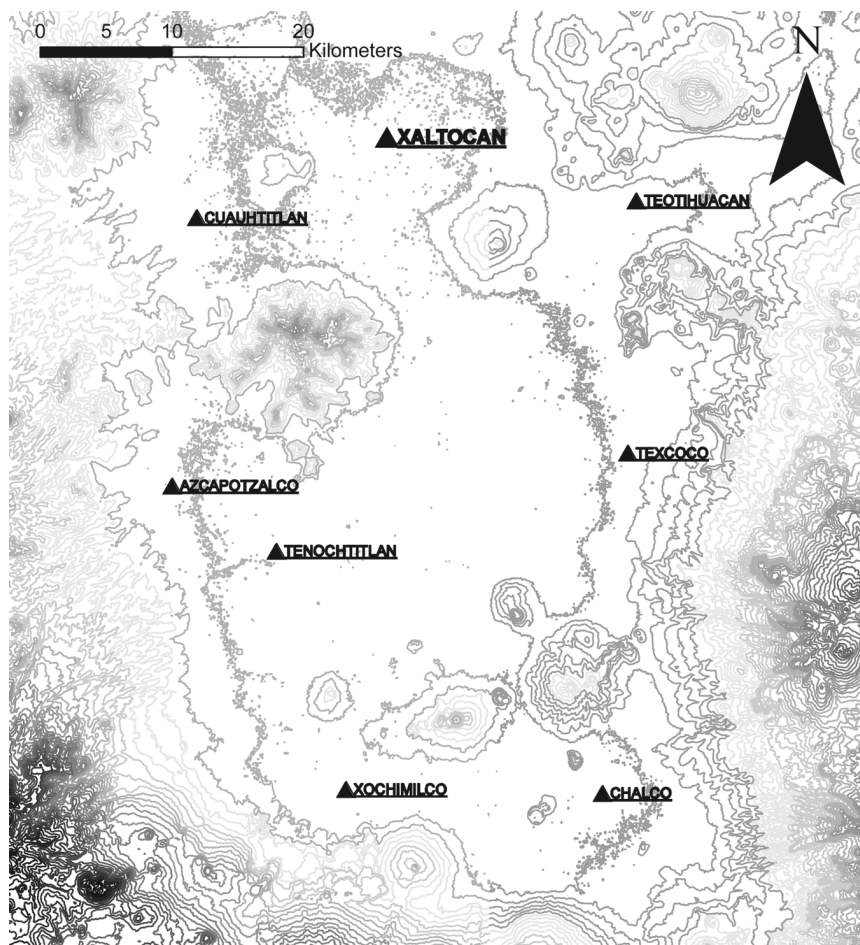
Although most studies of agricultural biodiversity center on measuring diversity in a range of taxa, there are justifications for focusing on maize (*Zea mays*). From a biological perspective, maize has been called a monster (Beadle 1980). It is completely reliant on humans for reproduction but can also be cultivated in a wide variety of ecological settings. Mexico is home to many indigenous land races of maize that exhibit morphological differences based upon genetic and ecological factors (Anderson and Cutler 1942; Benz 1986; Sánchez González 1994; Welhaussen et al. 1952). It is possible to study maize at the morphological level to ascertain the possible races of maize present in archaeobotanical assemblages as well as the production of maize in specific ecological contexts (Benz 1994; Bird 1994; Johannessen et al. 1990; Turkon 2006). From a political perspective, maize has been labeled a tyrant (Simpson 1967). Maize is economically and politically versatile. It can be dried and stored and processed into a range of foods. Maize can also be easily converted, either into the energy needed for brute force or into the wealth items needed to finance political endeavors (D'Altroy and Earle 1985).

BACKGROUND TO POLITY AND AGRICULTURE AT XALTOCAN

Xaltocan is located in the northern Basin of Mexico on an anthropogenic island in the now-drained lakebed of Lake Xaltocan (Figure 1). Xaltocan was one of several independent city-states of the Early to Middle Postclassic periods in central Mexico. Archaeologically, settlement of Xaltocan began in the tenth century C.E. (Brumfiel 2005; Carrasco 1950; Gibson 1964: 10). Within two centuries, however, Xaltocan controlled much of the northern Basin of Mexico (Carrasco 1950). At its height, the kingdom had more than 5,000 local inhabitants (Brumfiel 2005; Sanders et al. 1979: 151). Rulers intermarried with nobles from other sites, and archaeological evidence suggests an economy of local production, market trade, and tribute (Brumfiel 2005).

During the fourteenth century C.E., Xaltocan became embroiled in a lengthy conflict with the neighboring Tepanec kingdom of Cuauhtitlan (Velázquez 1945). In C.E. 1395, Cuauhtitlan obtained the aid of its more powerful Tepanec ally, Azcapotzalco, as well as Mexica mercenaries, and was able to finally conquer Xaltocan (Carrasco 1950). Xaltocan's population is said to have fled, leaving the community abandoned for 30 years (Hicks 1994).

Xaltocan and environs eventually were incorporated into the Aztec empire. Unlike the other city-states conquered by the Aztec empire, however, Xaltocan

FIGURE 1. *Map of the Basin of Mexico*

had seen its independent political system collapse prior to the formation of Aztec imperialism. The area was repopulated by peasants with economic obligations to Tenochtitlan and its sister-city, Tlatelolco. Archaeological data from Xaltocan indicate a general decrease in Xaltocan's prosperity, the breakdown of previous ties with other polities, and its transformation into a tribute-producing, rather than a tribute-consuming, community (Brumfiel 2005). Residents appear to have paid tribute to Tenochtitlan, Tlatelolco, and Texcoco (Hicks 1994, 2005).

During Xaltocan's development as an independent polity, residents constructed and expanded a large, integrated system of elevated fields and canals, a form of agriculture locally known as chinampas (Morehart 2010) (Figure 2).

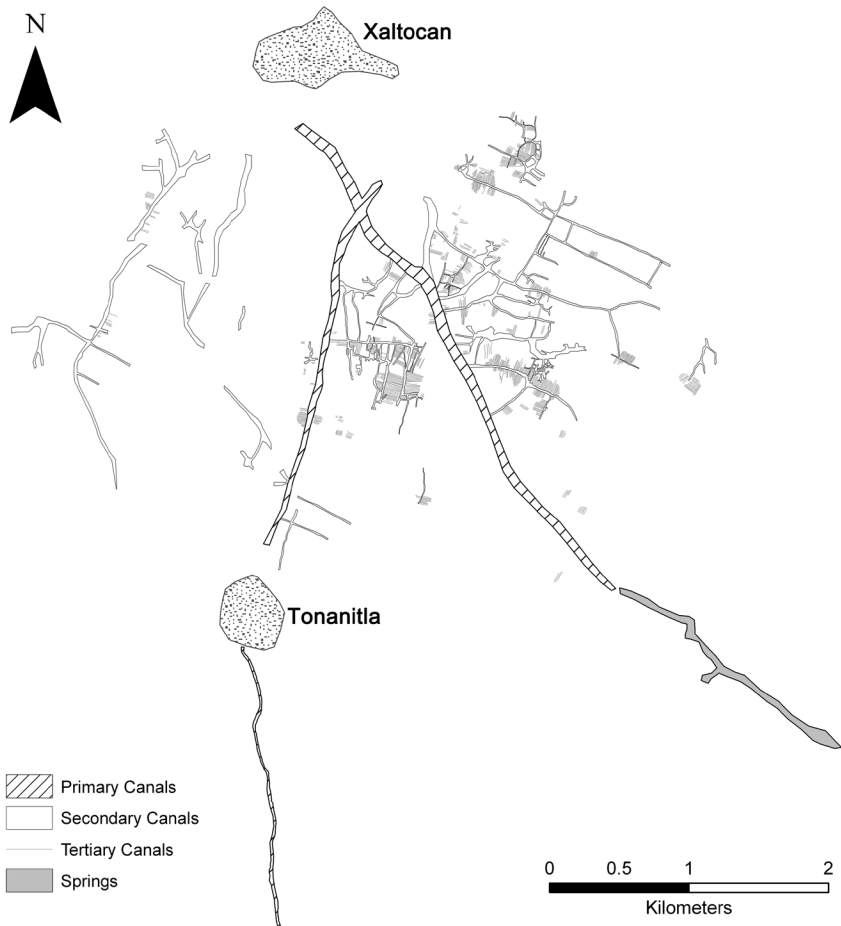


FIGURE 2. *Map of the chinampas of Xaltocan*

The agricultural system occupied about 1,500 ha and was dependent on a primary canal that transported freshwater into the brackish environment from distant springs at the foot of Cerro Chiconautla (Frederick et al. 2005; Morehart 2010). Chinampa farming likely permitted greater productivity than other forms of agriculture (Morehart 2010; Sanders 1957; West and Armillas 1950). Soil fertility was rejuvenated via organic-rich canal muck. The water in canals allowed the irrigation of plants and protected crops from seasonal frosts (Crossley 1999; see also Kolata and Ortloff 1989). Although certainly affected by preservation bias, archaeobotanical data suggest that maize was the dominant crop cultivated in the chinampas (Figure 3).

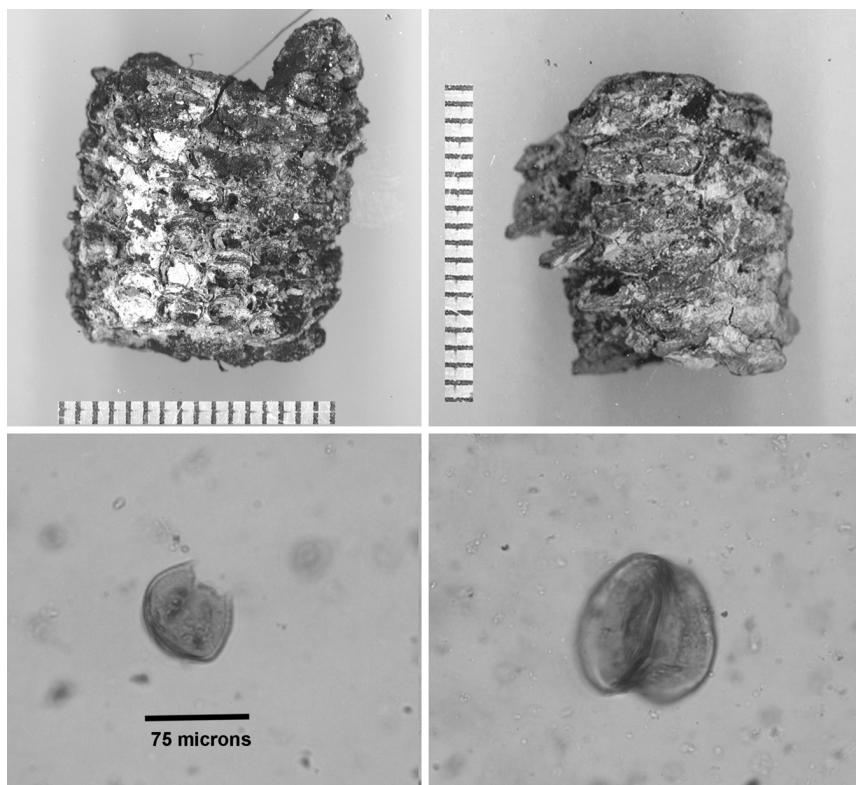


FIGURE 3. Maize (*Zea mays*) remains from Xaltocan's chinampas. Top: cobs; lower left: pollen grain; lower right: rondel, cob phytolith.

Although historic references exist on chinampa farming in the area during the Colonial period (Hicks 1994; Strauss 1974), archaeological data suggest that the bulk of chinampa farming was contemporaneous with Xaltocan's political independence and that it was largely abandoned following its conquest (Morehart 2010). Chronological data from the chinampas point to a Middle Postclassic timeframe. It is likely the bulk of chinampa farming occurred during the community's height (Phase 3, discussed later). First, virtually all Black on Orange pottery from surface collections in the chinampa zone is Early Aztec. Aztec II, Middle Postclassic pottery dominates the assemblage, followed by Aztec I. Virtually no Late Postclassic Black on Orange (Aztec III and IV) pottery, which dates to after Xaltocan's conquest and incorporation into the Aztec empire, has been recovered. Second, this pattern in the distribution of pottery types from surface collections is mirrored entirely by the ceramics recovered from excavations (Morehart 2010). Last, AMS dates on maize remains

from the chinampas fall within the Middle Postclassic (1200–1400 C.E.). Thus, taken together, the data from the chinampas suggest a predominantly Middle Postclassic time frame for chinampa agriculture.

DIVERSITY AND CHANGE AT XALTOCAN

To what extent did the political history of Xaltocan shape the diversity of maize cultivated and consumed in the community? During the Late Postclassic period the Aztec empire maintained a far-reaching, hierarchically structured tribute system that brought in both wealth and staple goods depending on the distance from the imperial capital (Berdan and Anawalt 1992; Berdan et al. 1996; Drennan 1984; Hassig 1985; Hicks 1992; Morehart and Eisenberg 2010). Indeed, in a letter written in 1544 to Charles I, King of Spain, the *encomendero* Jerónimo López observes that during the time of Mocteczuma “all the towns and provinces of his kingdom were forced to plant and there were overseers in his time to see if they were planted” (Paso y Troncoso 1939: 169). These overseers were most likely imperial officials, known as *calpixqueh* and charged with collecting or tallying tribute. To the extent that the later Aztec empire was founded on pre-existing political economic strategies in the Basin of Mexico (Berdan et al. 1996), one might expect a similar political impact on agricultural production at Xaltocan. Indeed, given the smaller regional size of Xaltocan’s state, the political involvement in agricultural production may have been even stronger and more direct than that of the largely hegemonic imperial strategies of the later Aztecs (see Hassig 1985).

Determining how mechanisms of production, distribution, and consumption affected agriculture is a challenge using archaeobotanical data (Morehart and Eisenberg 2010). In terms of tribute, two patterns are possible at the community level. First, as Xaltocan’s influence expanded in the northern Basin of Mexico, more and more tribute likely flowed into the center. Thus, we might see an increase in diversity as maize cultivated in various ecological settings entered Xaltocan. Second, the development of chinampa agriculture possibly was linked to Xaltocan’s political growth, suggesting a concerted effort to be agriculturally self-sufficient. Thus, we might see a decrease in diversity as local chinampa farmers absorbed the burden of tribute and increasingly became the economic backbone that financed Xaltocan’s political economy. Conversely, given Xaltocan’s position both as a tributary and a market center in the Middle Postclassic period, the diversity of maize might have increased, and it might be virtually impossible to determine the networks of production, distribution, and consumption responsible for patterns in the archaeological record.

These issues can be addressed by considering patterns in maize variability across time. I studied maize remains recovered from excavations in the

community of Xaltocan as well as maize remains recovered from the chinampa system. A total of 175 maize specimens from 17 test pits were analyzed from the community of Xaltocan. Samples were from archaeological deposits assigned to different chronological phases of the site's development. Thirty-two specimens were from Phase 1 (A.D. 900–1100), which corresponds to the site's initial settlement in the Early Postclassic period. Forty-six specimens were from Phase 2 (A.D. 1100–1300), dating to Xaltocan's initial development as a political center. Fifty-two were from Phase 3 (A.D. 1300–1390), which documents the site's maximum size and political power during the Middle Postclassic. Finally, 45 were from Phase 4 (A.D. 1430–1521), which corresponds to the community's incorporation into the Aztec empire following its conquest and possible abandonment.

The maize data from Xaltocan's chinampa system come from excavation test pits and geomorphological trenches. A total of 55 maize specimens from 15 excavation units and 5 geomorphological trenches were studied. As just mentioned, several lines of data suggest that chinampa agriculture occurred primarily during the Middle Postclassic in Phases 2 and 3.

I examined variability by measuring cob morphological differences in maize remains from each phase. The morphology of maize is the product of genetic, environmental, and other developmental factors (Adams et al. 1999; Benz 1994; Goodman and Paterniani 1969; Turkon 2006). Thus, variability in the maize sample might reflect either the presence of different maize types or the presence of maize cultivated in different ecological settings. The key measurements include cupule width, cupule length, cupule aperture width, and cupule wing width. This repertoire of variables includes the most common attributes measured to examine maize variability present in archaeobotanical assemblages. These attributes were selected because it was possible to record them regardless of the completeness of the specimen.

I quantify diversity and variability in the maize sample by employing a diversity index and principal component analysis. Most diversity indices rely on differences in the number of members of taxonomically discrete units (Barbour et al. 1987; Magurran 2004). Although different maize types can analytically be treated as different taxa (Popper 1988), this is difficult without a priori knowledge of the specific varieties of maize present. To tackle this problem, a K-means cluster analysis was used to determine the numbers of maize groups. K-means analysis is a multivariate partitioning method that creates clusters by calculating cluster means (centroids) depending on the specified number of clusters and assigns cases to each cluster on the basis of the distance of each case from the cluster mean (Shennan 1997: 251). Each cluster can be interpreted as a separate taxon or variety. Analytically, the actual number of clusters in the data is less relevant than the resulting diversity index. That is, if different clustering solutions

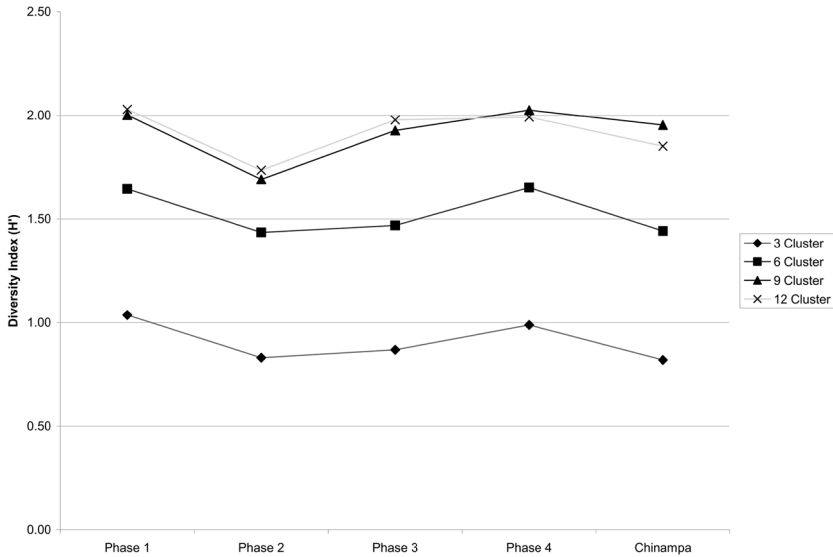


FIGURE 4. *Shannon diversity index values for each cluster solution.*

result in relationally consistent indices, we can obtain an approximate measure of diversity between analytical units regardless of the initial clusters. We conducted four separate analyses using 3, 6, 9, and 12 initial clusters. The Shannon diversity index, which measures the relationship between species richness (in our case, the number of clusters) and evenness (in our case, the number of individual cases assigned to a cluster), was employed to assess diversity, (Morehart and Eisenberg 2010).

Figure 4 presents the diversity indices for each analytical unit for every cluster solution. Although the actual index values vary depending on the number of clusters established for each solution, qualitatively there appears to be consistency irrespective of the cluster solution employed. That is, Phases 1 and 4 are consistently the most diverse; Phase 2 and the chinampa group are less diverse; and Phase 3 is in between, though less diverse than Phases 1 and 4. These values are assessed only qualitatively, however. There is little consensus on how to test significant differences between the resulting diversity indices (Hutcheson 1970; Magurran 2004: 108; Popper 1988). The consistency of the diversity indices, however, offers insight that can be formally evaluated by principal component analysis (PCA).

PCA generates synthetic variables by extracting underlying orthogonal axes of variation (Shennan 1997: 297–300). All four key measurements were included in the analysis. Component 1 encompasses 60 percent of the variance and seems

to represent the general size of cupules. Component 2 encompasses an additional 22 percent of the variance. A scatter plot of all cupules plotted with PC 1 against PC 2 and with 95 percent confidence ellipses surrounding each analytical unit can be examined visually to assess variability (Figure 5). Phase 1 cupules show the highest degree of variance in relation to PC 1 along the x axis, suggesting more variability. Phase 2 cupules display reduced variability along the x axis, though with greater values, which suggests overall larger sized cupules. Phase 3 shows a clear reduction of variability along both axes, suggesting decreased variability but also smaller cupules. The range of variability in cupules from the chinampas mirrors Phase 3, especially along the x axis. Phase 4 cupules display an increase in variability along both axes, especially in relation to PC 1, though slightly less than Phase 1 cupules.

In short, general trends in the distribution of data suggest greater variability in Phases 1 and 4, reduced variability in Phases 2 and 3 and in the chinampa data, larger-size cupules during Phase 2, and smaller Phase 3 and chinampa cupules. These patterns are generally consistent with the previous diversity analysis.

These qualitative considerations are evaluated using Levine’s robust test for equality of pair-wise variance and pair-wise, two-tailed t tests on PC 1, the

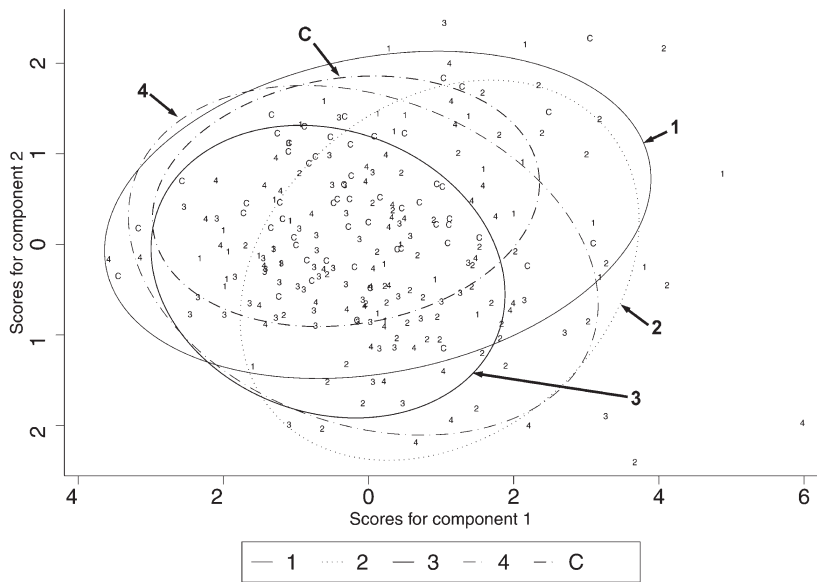


FIGURE 5. Scatterplot of individual cases against PC 1 and PC 2 (phases numbered, C for Chinampa). Ellipses are 95% confidence ellipses surrounding the respective groupings.

component that encompasses most of the variance. Table 1 displays the results of the pair-wise significance test between each group, with the results of *t* tests on the top half and the results of the Levine test on the bottom. The only significant differences in variance between groups are between Phase 1 and Phase 3 and between Phase 1 and the chinampas, indicating that Phase 1 variability is significantly greater than that in Phase 3 and in chinampa cupules. Although the difference is insignificant, Phase 1 shows a greater trend toward increased variability than does Phase 2. With a conservative Bonferroni correction for multiple-tests employed, however, the alpha value is reduced to 0.005, and, consequently, none of the results reject this more rigorous null hypothesis of equal variance. Regardless, it is important to note the magnitude of differences and not to dogmatically accept arbitrary statistical cut-offs (Ziliak and McCloskey 2004), especially when dealing with sample sizes that are necessarily limited.

TABLE 1. Results of Levine's Robust Test of Equality of Variance (Bottom) and the Two-tailed *t* Test of Unequal Variance (Top)

	1	2	3	4	C
1		-2.18 (0.03)*	1.84 (0.073)	0.48 (0.629)	1.16 (0.252)
2	3.29 (0.073)		5.82 (0.000)**	3.34 (0.001)**	4.77 (0.000)**
3	7.64 (0.007)**	1.26 (0.265)		-1.65 (0.103)	-.10 (0.320)
4	1.86 (0.177)	0.3 (0.853)	1.24 (0.268)		0.79 (0.429)
C	5.07 (0.027)*	0.26 (0.610)	0.36 (0.548)	0.38 (0.537)	

NOTE: There is one asterisk for significance at the .05 level and two for the .01 level. Italicized values are approaching the .05 significance level (<0.10). Significant values are displayed without taking into consideration the Bonferroni correction.

The two-tailed *t* test show more significant differences between group means. The mean for PC 1 for Phase 2 is significantly different from that for every other grouping. This result is due to a higher positive mean value of PC 1 for Phase 2 than for the other groupings. With the exception of the test between Phases 1 and 2, all the results remain significant at the more conservative level (0.005) set by the Bonferroni correction. In short, the *t* test suggests that Phase 2 cupules are significantly different from the other groupings, apparently due to greater *size*.

DISCUSSION

The variability in maize at Xaltocan provides insight into the relationships between political economic change and the standardization of agricultural production. The low diversity values and greater variability during Phase 1 suggests the production or consumption of maize from a wider range of ecological contexts. Given that this time predates the establishment of Xaltocan as a powerful kingdom and the initiation of chinampa agriculture, farmers likely cultivated maize in ecologically diverse areas, possibly via agriculture along the lake shore, the alluvial plain, and the nearby foothills.

Phase 2 maize is less diverse than Phase 1, and its mean differs from those for all the other groups. This difference is a reflection of larger size. Phase 2 cupules are wider and longer and have wider apertures. Because cupules house the grains, larger cupules likely correlated with larger grains (see Benz 1986: 52). The lower diversity indices of Phase 2 in comparison with Phase 1 might indicate the development of Xaltocan's market system, which could have increased community-wide homogeneity (Garraty 2009; Hirth 1998). Conversely, the larger maize during Phase 2 may reflect the initiation of chinampa agriculture, which provided crops with greater amounts of available water and offered an ecological context for more productive maize varieties in terms of grain size.

The diversity of Phase 3 maize is also low, and the range of variability is significantly less than that for Phase 1 maize. This pattern of variability is mirrored in the chinampa maize, and cupules from both analytical units occupy similar dimensional spaces, especially in relation to Principle Component 1. The similarity between the two analytical units diminishes the possible role of tribute and market. In other words, it seems that the majority of maize processed and consumed in the community during Phase 3 came not from distant tributaries or agriculturalists in other communities participating in the market but from local chinampa farmers.

Chinampa farming intensified greatly during this time, and farmers may have begun to cultivate faster-maturing varieties of maize that had smaller ears. Furthermore, smaller cupule sizes, especially widths, may have correlated with increased row number, indicating the production of maize ears with smaller but more numerous grains (see Benz 1986: 51). The fact that the community appears to have been self-sufficient with regard to maize consumption likely shaped its position in regional tribute and market systems, placing emphasis on the extraction and circulation of items not produced locally (see Morehart and Eisenberg 2010).

The decreased variability and the smaller maize size suggest increasing standardization of maize production. Agricultural intensification possibly was tied to the need to produce tribute for local elites. As discussed earlier, Xaltocan

came into conflict with the neighboring kingdom of Cuauhtitlan, and much of Phase 3 at Xaltocan was marked by war. Such conflict periodically disrupted regional tribute and market networks (Brumfiel 2005: 359) and possibly limited farmers' abilities to cultivate lands in other locations. This unstable climate likely led to an agropolitical strategy that stressed local self-sufficiency. The burden on chinampa farmers may have been not simply the result of a balance between subsistence requirements and the need to maintain political institutions but also demands to finance the needs of a kingdom at war.

During Phase 4, residents at Xaltocan were subordinate to the Aztec empire. The data on Phase 4 maize suggest a return to high levels of variability. The increase in maize variability is somewhat unexpected given the previous discussion of the impact of tribute on maize production but can be viewed in the context of the more expansive Aztec empire. Brumfiel (2005) documented an increase in small spindle whorls used to produce cotton cloth in Phase 4, which was probably due to tribute requirements. Farmers possibly had fewer burdens on their own maize production and, given the reduced scale of chinampa farming, likely diversified their agricultural strategies across the landscape in ways similar to those used in Phase 1. On the other hand, the Late Postclassic period saw the highest levels of population density in central Mexico (Sanders et al. 1979), which probably limited the available land in surrounding areas. Increased variability may be the result of a need to obtain subsistence items from surrounding market locations.

Finally, if we examine the diversity index values of archaeological phases at Xaltocan using a more complete representation of cultigens archaeologically recovered from the community, an interesting pattern emerges (see McClung de Tapia and Martínez Yrizar 2005: 213) (Figure 6). As the diversity of maize decreases between phases, especially between Phases 1 and 2, the overall species diversity at the community level decreases also. This suggests that the political impact on agricultural diversity may have been more systemic and not exclusively centered on maize. That is, as farmers cultivated more maize, they spent less time cultivating other taxa. Residents became increasingly reliant upon maize agriculture, suggesting a complex set of entanglements and structures of dependence. Another precipitous drop in diversity can be seen between Phases 3 and 4, and this may be due to increased general impoverishment of later residents living under the Aztec empire (see Brumfiel 2005).

CONCLUSION

At Xaltocan, the standardization of maize production was not simply a matter of the generalized development of full-time agricultural specialists (see Sanders et al. 1979). Instead, it seems to have been related to (1) the growing needs to

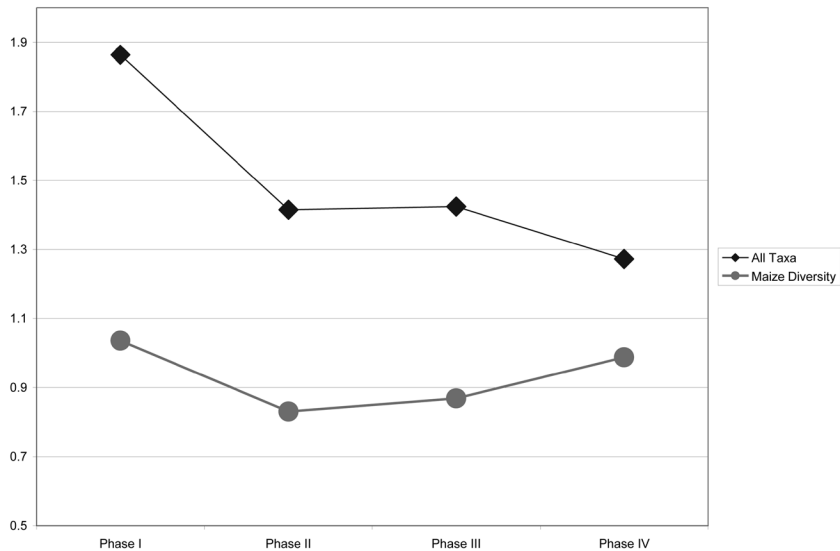


FIGURE 6. *Shannon diversity index values, by phase, for a range of likely cultigens recovered from central Xaltocan against the diversity index values for maize (see Figure 4, three-cluster solution).*

finance the economic structure of a political state, (2) the production of faster-maturing varieties of maize with more numerous rows, (3) a decrease in the range of ecological contexts of agriculture, (4) greater intensification in agricultural contexts, namely the chinampa system, and (5) a decrease in the overall diversity of crops present in the community as a whole.

As Zimmerer (1993) discusses in his work on the effect of Inca tribute on agricultural biodiversity, farmers occupy a dual position in relation to state institutions. On one hand, they must produce a surplus for tribute. On the other hand, they must keep production above the economic margin in order to maintain subsistence requirements and to reproduce the systems of production (Wolf’s [1966] “replacement fund”) (see Scott 1976). The ability of farmers to maintain diversity can promote the persistence and resilience of their economic strategies over the long term (Netting and Stone 1995).

Where does the story lead from here? One might see the theme of this essay as centered mainly on a critique of the romantic vision of past agriculturalists as essential stewards of their ecological milieu. Thus, one might expect me to adopt the opposite view that stresses how past people did follow unsustainable practices that degraded their environments (Denevan 1992; Lentz 2000). Yet, the story is more complex, marked by limitations in data and generally characterized

by that universal historical reality that resists simple categorization. For instance, although diversity decreased as Xaltocan developed, this does not mean that farmers were necessarily less well off. In fact, later residents living under the Aztec empire seem to have occupied a much more impoverished and precarious position (Brumfiel 2005, but see Pérez Zevallos 1990). Xaltocan's chinampa system collapsed or at least declined greatly by the early Colonial period (see earlier discussion). But the kingdom was conquered, and the social and political relationships that managed the organization and systemic maintenance of land and water (of which farmers were active constituents) broke down. Thus, it would be too simple to say that the decreased diversity of maize and other crops led to degradation and collapse. Instead, the reduced agricultural diversity points us to where archaeological and anthropological work on standardization has historically pointed us: to the political, social, and economic fabric. The standardization of agriculture developed as farming households and their relationships became increasingly tied to and dependent upon the stability and sustainability not of the ecological milieu but, instead, of the state itself (Morehart 2010).

As a comparative concept, understanding standardization is more complex than simply identifying past societal formations and economic systems. Its implications stretch beyond economic factors to encompass cultural artifacts of various scales and degrees of tangibility, from religious ideologies to entire landscapes. James Scott (1998) recognized standardization as a process he referred to as “rendering legible the illegible” to characterize the expansion of capitalism's commodifying and hegemonic logic across the globe. The view of standardization thus increasingly serves as a model for understanding the effect of the state, empire, and, today, colonialism and globalization on the human experience.

Research on standardization offers a useful historical framework to talk about the relationship between biological diversity and changing social and political processes. Today, the reduction in biodiversity can occur as an unintended consequence of mismanagement and broader economic policies or conditions, or it can be an established and deliberate goal of specific institutions, such as modern transnational corporations (such as Monsanto). In other words, like standardization, the reduction of biodiversity is caught up in complex processes of production, consumption, domination, and dependency. Framing changes in agrobiological diversity as a process of standardization expands the comparative potential of this concept and unequivocally exposes it as social and political.

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From Historical Ecology to Prehistoric Economy

Modeling the Caloric Landscapes of the Past

A number of behavioral ecological models have been proposed to help us better understand how humans interact with, adapt to, and manipulate their environment. Optimal Foraging Theory (OFT) is perhaps the most often cited and, with respect to archaeology, is intended to specifically invoke the idea that humans will always seek to increase efficiency in the area of subsistence (MacArthur and Pianka 1966; Emlen 1966; Bettinger 1980; Stephens and Krebs 1986; Simms 1987; Kelly 1995; Winterhalder and Kennett 2006). OFT is generally applied within the context of Central Place Theory (CPT; Christaller 1933), referencing particularly the concept of range maximums and the optimization of resource collection and trade, that is, Central Place Foraging (CPF; Orians and Pearson 1979; Stephens and Krebs 1986; Jones and Madsen 1989; Metcalfe and Barlow 1992; Bettinger et al. 1997; Bird 1997; Grayson and Cannon 1999; Zeanah 1996; Thomas 2008).

The Diet-Breadth Model (DBM) is an elucidation within the broad spectrum of OFT that asserts that a variety of energy sources (for example, forage species) will be selected for their caloric and nutritive return on the basis of their relative lengths of processing and collection times (Hames and Vickers 1982; O'Connell and Hawkes 1984; Winterhalder 1987; Smith 1991; Grayson and Delpech 1998; Thomas 2008). Presumably this also applies to the investment of time and energy in plant and animal husbandry activities among groups that use domesticated resources. DBM introduces the idea that maintaining subsistence efficiency is a cumulative cognitive planning exercise. OFT and DBM have been further linked to Prospect Theory (PT; Kahneman and Tversky 1979; Tversky and Kahneman 1992; Wakker et al. 2007) in that they embody the notion that subsistence and settlement decisions are consciously based on an assessment of the risks involved in collection behaviors and a perception of the success of the outcome, especially with regard to future payoffs.

All of these theoretical models are simplifications of some aspect of the dynamical system of human subsistence and settlement that functions as a mechanism for acquiring, maintaining, and trading sources of potential energy, that is, calories. The actions of collecting, maintaining, and storing potential energy sources, as well as representations of them, can accumulate to produce strikingly complex patterns in the archaeological and anthropological records. In short, it is the manipulation of the caloric surplus resulting from successful subsistence activities (more specifically, the planning for and speculation on future caloric returns) that provides the ability to redirect energy into nonsubsistence actions. Furthermore, through Geographic Information Systems (GIS) modeling of the relative value, cost, risk, and predictability of the fundamental caloric elements, we can reconstruct and interpret some aspects of how not only subsistence but also other kinds of spatially bound economic decisions are made.

THE SPATIAL DISTRIBUTION OF PHYSIOLOGICAL IMPERATIVES

The foundation of human subsistence is first and foremost to meet the basic physiological needs of survival. In order to survive, people initially need to find sufficient oxygen to breathe. However, in almost all conditions any person can assume with near certainty that sufficient oxygen will occur anywhere; therefore, its spatial distribution is not typically of concern. It is highly unlikely that anyone would develop or maintain a cognitive map of the spatial distribution of oxygen sources or the composition of atmospheric gases. A cognitive map is an entirely cognized perception of where resources (or physiological imperatives) can be acquired or where risks to their attainment would be incurred within the spatial area of the agent's familiarity. This is essentially an ongoing internal cost-benefit analysis for survival or subsistence. We all maintain cognitive maps for many purposes, both conscious and subconscious (see Cohen 1985; Downs and Stea 1973, 1977; Gärling and Evans 1991; Ittleson 1973; Kitchin and Freundschuh 2000; Kitchin and Blades 2002; Moore 1979; Saarinen et al. 1984), and cognitive maps for physiological imperatives would be among the most important.

The second basic human physiological need is to maintain sufficient body temperature; either through the utilization of shelter or through the manufacture and wearing of clothing. Although the elements that can be used to create shelter or clothing are not necessarily evenly spatially distributed, the potential options are such that there is a very high predictability for finding sufficient body-temperature-regulating methods in nearly all environments once the knowledge to do so is acquired and transmitted among family and community members. Particularly warm environments are much more forgiving in this respect, while cold ones are less so. The importance of knowing and using

the spatial distribution of shelter resources (that is, having a cognitive map of such things) changes with the available technology, the average temperature, and the season and is much more important in colder climates. In all cases, the spatial distribution of fixed point shelter locales (that is, caves and rockshelters) becomes less limiting once one knows how to manufacture portable shelters with the available raw materials. Likewise, the technological innovation of using vegetal fibers to create textiles greatly reduces the dependence upon prey animals for the manufacture of clothing. These innovations came about well back in human history, and close, conscious ties between human settlement patterns and the spatial distribution of body-temperature-regulating resources and therefore the importance of cognitive maps associated with them have gradually diminished with the increasing diversity of options.

The third physiological imperative is to maintain hydration. Water sources are distributed unevenly across the environment, but finding them is typically a simple matter and quite predictable when the generalities of topography, gravity, rainfall, and groundwater are understood. The abundance of water sources may greatly vary, but knowing where to acquire water is perhaps one of the most fundamental concerns for all people, and there is naturally a strong correlation between human actions and the proximity of water sources. However, it is very unlikely that the distribution of water sources is an essential *conscious* limitation on where human actions occur, with the exception of when they occur in very arid environments. This means that a cognitive map of water sources is extremely important, but in general it is largely unchanging, probably fluctuating only seasonally and then typically only slowly. Water sources are, in essence, fairly stable and predictable. Once a sufficient source of water is identified and its productivity and seasonality are understood, then water collection is routine even when human actions are limited by its proximity.

Cognitive maps of water sources are therefore not typically complex, nor are they likely to be at the forefront of conscious spatial decision making, despite the overarching importance placed upon proximity to water by traditional archaeological predictive models. Limitations on finding new water sources may be locally diverse but are generally going to be evaluated “on the fly,” so to speak, when immediate knowledge of water sources is not available but very good predictions of where water sources are likely to occur are understood. Such limitations are also ameliorated by the development of water transport and storage technology (such as the use of skin bags, bladders, and pitched watertight basketry, as well as the development of ceramics, wells and cisterns, and, ultimately, aqueducts, plumbing, reservoirs, and water-treatment facilities).

The fourth and final physiological essential is energy, the intake of sufficient food to counterbalance the burning of calories from everyday activities.

Additionally, a range of nutrients is required for survival, and this requires either that diet focus on a high-enough link in the food chain that most necessary nutrients are already accumulated or that it have sufficient breadth to acquire the proper range of nutrients from a variety of lower-level sources. Calories are perhaps the most unevenly distributed and least predictable physiological element necessary for survival. All animals have to maintain a positive caloric balance to survive, and the knowledge of where and how to acquire those calories is of extreme importance. OFT, CPF, DBM, and PT are observations on the basic rules for how to maintain that positive balance.

Ultimately, as species strive to maintain a positive caloric/nutritive balance, a driving motivation to do two things exists: (1) to increase the caloric/nutritive yield from acquired food, and (2) to decrease the caloric expenditure of acquiring and processing food. All actions involving the fourth physiological imperative are underlined by these two basic rules. Going back into human/hominid history, it is clear that a series of innovations and adaptations has allowed us to continually increase efficiency in gathering calories (foraging), while also sufficiently meeting the other physiological imperatives. Once humans acquired the ability to plan for and speculate upon future caloric derivatives, these driving motivations led to the creation of a significant caloric surplus. Surplus, in this sense, means any amount of calories over the number necessary to survive and reproduce. Reproduction can be thought of as the fifth physiological imperative. It is not necessary for the survival of the individual, but it is for the survival of the family, community, and species over the long term.

Reinvesting that surplus energy into further increasing efficiency only leads to additional surplus. It becomes inevitable that all other sociological imperatives, experiments, interactions, contracts, and institutions derive from the ability to accumulate, store, and redirect this energy surplus into other (non-subsistence and nonreproductive) activities. Foraging efficiency, in essence, produces the energy necessary to create all of the material and social aspects of human culture. At the very heart of extremely complex human behaviors and interactions, then, are the acquisition, control, manipulation, and exchange of surplus calories in various forms. Continually improving the efficiency of foraging for or harvesting these calories is akin to managing a bank account; the deposits need to exceed the expenditures. But since only a certain number of those calories are needed for personal, family, and community survival, the surplus is exchanged for other things (often in the form of a proxy representation, that is, a currency). Calories, though, are inherently tied to the landscape; they can come only from other organisms. Understanding their spatial distribution and controlling their harvest and exchange become the primary means to invest in, predict, and profit from current and future yields.

RE-CREATING PAST HISTORICAL ECOLOGIES

Putting aside any further (only somewhat facetious) argument that all of human society can be thought of as the by-product of consistently improving caloric efficiency, I would like to focus on how we can re-create the historical ecologies of the past. The goal is to see how people interfaced with their environment, what subsistence and settlement choices they made, and why they made them and to interpret the larger economic relationships that arise out of the spatial distribution of people and the calories they harvest. This approach attempts to re-create the intentionality of past spatial decisions and, ultimately, to understand their causality. The goal is not just to discern where sites or activity areas are likely to be found in general but why certain kinds of behaviors are likely to occur in specific locations and what relationships exist between settlement and the spatial distribution of potential energy sources. Humans interact with their surroundings, extract resources, and alter them in a consistent and observable pattern of behaviors (see Crumley 1994). To do this they develop cognitive perceptions of the landscape and project where existing and future caloric returns are likely to be the most productive and the potential surplus the greatest. Analyzing those perceptions leads to an understanding of the causality (see Salmon 1998) behind past, as well as existing, subsistence economies.

To understand how cognitive maps of the perceptions and potentiality of caloric returns (what may be referred to as “caloric landscapes”) are used, we need to first re-create what those landscapes were at any given time. Notably, a model representing caloric landscapes would have to consider not only the potential habitats of a given foraging target (plant or animal) but also the intensity of the correlation with key elements of those habitats, the variable density of the target population within them, the clustering of individuals, the seasonal or periodic limitations on harvesting, the available technology used to acquire and process them, and, obviously, the costs of reaching, acquiring, and transporting those calories. Any one target species is also subject to placement within a larger context of the entirety of species known or likely to have been consumed, that is, their proportional representation in the diet. This includes their selection for nutritive return beyond caloric value, personal and societal preference, and the tradability of the resource and its resilience to intensive harvesting.

To illustrate various points in this discussion, I use GIS surfaces and preliminary results from a study that focuses on the Georgia Coastal Zone (the 11 counties in Georgia that are within 100 km of the Atlantic) and includes up to 25 km offshore (Whitley 2013). This study covers 4,669,484 acres (both land and water), and the framework exists as three distinct models: (1) the Habitat Model (HM), an interpretation of the intensity of the correlation between a

given forage category and any map unit for each month of the year, based on the strength and distribution of key elements (attractors) in their habitat; (2) the Available Caloric Model (ACM), an interpretation of the total number of calories that could be expected in any map unit, given a habitat model value and population density estimates for each forage category for each month of the year; and (3) the Returned Caloric Model (RCM), an interpretation of the number of calories for each forage category for each month that could be extracted from any map unit, given the available calories, the technological limitations, and the costs of acquiring, processing, and transporting the targets.

The Habitat Model is defined by 37 forage categories (Table 1), some of which are individual species (such as “white-tailed deer”), while others are combinations of numerous species based on family or genus groupings (such as “freshwater turtles”) or on size/habitat limitations (such as “large saltwater fish”). These groupings include both wild faunal and floral resources, as well as domesticated (or semidomesticated) species. Ultimately, weighted additive formulas were developed for each forage category using 15 baseline environmental attractors (see Table 1, derived from the USFWS National Wetlands Inventory maps, the NRCS Soils Survey Geographic Database, the USGS National Elevation Dataset, the NOAA Hydrographic Survey Dataset, the GDNR Land Use/Land Cover data, and the USEPA Level 4 Ecoregions Data). The strength of the attractors (that is, formula weights) were based on both qualitative and quantitative assessments of preference derived from sources such as Thomas (2008), Smith (1992), Reitz et al. (2010), NARSAL (2010), Georgia DNR (2010), and nearby states’ online resources giving population estimates or biological statistics. They were broken out by month of the year as well. The results are a series of 444 individual GIS surfaces (37 forage categories * 12 months), each of which covers all 4,669,484 acres with a resolution of 30 m (900 sq m). Each of the 20,996,530 data points (referred to here as “map units”) has a decimal value ranging between 0 and 1, which represents the predicted habitat suitability for each forage category for each month for that 900 sq m location. Figures 1 and 2 are examples of detailed views of several of the HM surfaces (it is impossible to illustrate here any surface in its entirety as a legible image).

TABLE 1. Forage Categories and Environmental Variables
Used in the Georgia Coast Study

FORAGE CATEGORIES	
Very Large Saltwater Fish	Wading Birds
Large Saltwater Fish	Sea Turtles
Medium Saltwater Fish	Freshwater Turtles

Table 1 continued

FORAGE CATEGORIES

Small Saltwater Fish	Reptiles
Very Small Saltwater Fish	Amphibians
Large Freshwater Fish	Shellfish
Medium Freshwater Fish	Sea Turtle Eggs
Small Freshwater Fish	Maize (<i>Zea mays</i>)
Very Small Freshwater Fish	Beans (<i>Phaseolus vulgaris</i>)
White-tailed Deer (<i>Odocoileus virginianus</i>)	Squash (<i>Cucurbita pepo</i>)
Black Bear (<i>Ursus americanus</i>)	Amaranth (<i>Amaranthus spp.</i>)
Alligator (<i>Alligator mississippiensis</i>)	Sunflower (<i>Helianthus annus</i>)
Wild Turkey (<i>Meleagris gallopavo</i>)	Maygrass (<i>Phalaris caroliniana</i>)
Raccoon (<i>Procyon lotor</i>)	Sumpweed (<i>Iva annua</i>)
Opposum (<i>Didelphis virginiana</i>)	Acorns (<i>Quercus spp.</i>)
Rabbits (<i>Sylvilagus spp.</i>)	Hickory Nuts (<i>Carya spp.</i>)
Squirrels (<i>Sciuris spp.</i>)	Cattail/Bullrush (<i>Typha spp.</i>)
Upland Birds	Chenopods (<i>Chenopodium spp.</i>)
Waterfowl	

ENVIRONMENTAL VARIABLES

Water Availability	Water Depth (midlevel)
Water Salinity	Water Depth (deep)
Soil Texture	Elevation (salt and back marshes)
Soil Fertility	Elevation (island and river bluff margins)
Vegetation Density	Elevation (Princess Anne formation)
Vegetation Type (deciduous)	Elevation (Penholoway/Talbot formations)
Vegetation Type (live oak)	Elevation (Wicomico formation)
Water Depth (shallow)	

To transform the Habitat Model into a caloric expression (the Available Caloric Model), a series of variables were generated, including the population density of each forage category (per 30 m map unit), their average size, the ranges in weight by gender, the adult/juveniles and gender ratios, the usable calories per kg, the average number of offspring, the mean birth months, time until sexual maturation, prime harvest months, crop yield, and fallow cycle. All of these assessments were based on the same sources of information that were mentioned

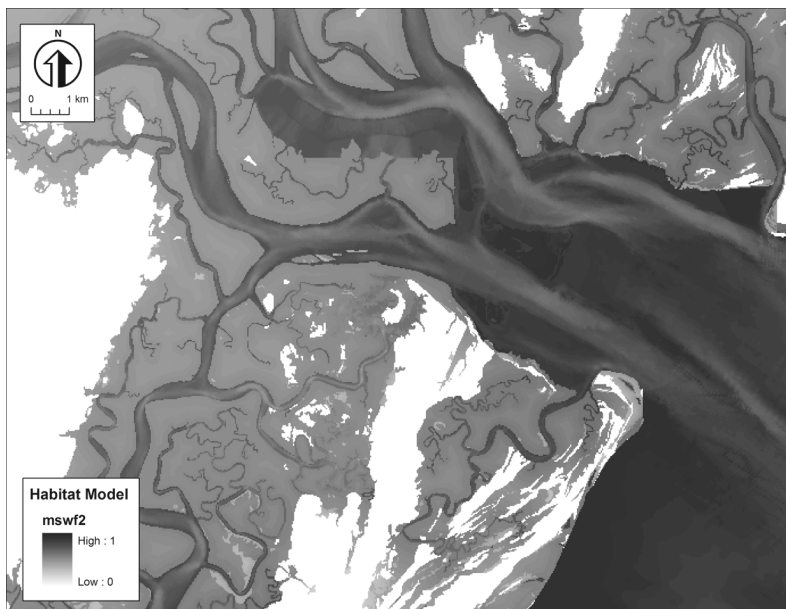


FIGURE 1. Detail of the Habitat Model for medium saltwater fish (February), showing the northern end of Ossabaw Island.

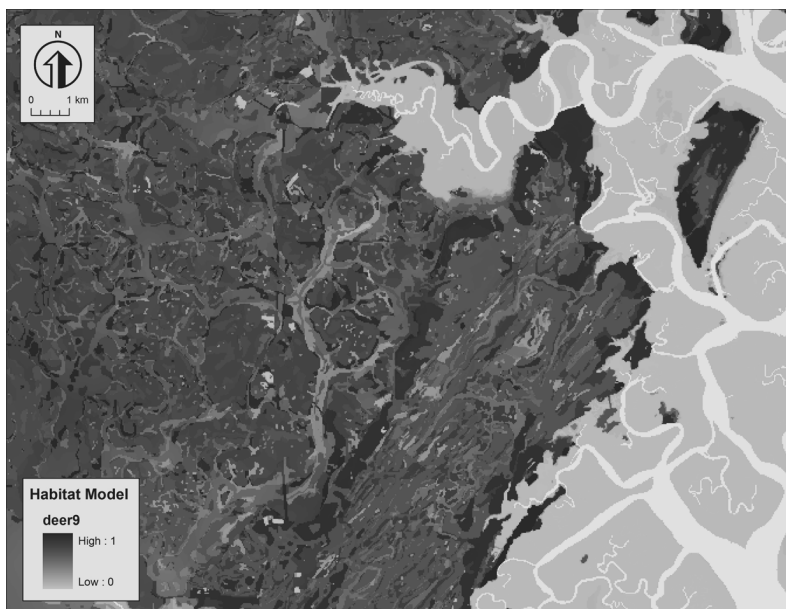


FIGURE 2. Detail of the Habitat Model for white-tailed deer (September), showing the mainland opposite Sapelo Island.

TABLE 2. Available Caloric Maximums for Each Forage Category by Month per Prime 30 m Map Unit.

FORAGE CATEGORY	Available kcal/30m unit of prime habitat											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
VLarge Saltwater Fish	1,018	1,356	1,755	2,462	3,653	4,723	4,723	3,653	2,814	2,006	1,356	1,018
Large Saltwater Fish	807	1,025	1,436	1,995	2,864	3,614	3,614	2,864	2,128	1,532	1,093	807
Medium Saltwater Fish	904	983	1,478	2,133	2,729	3,187	3,054	3,160	2,384	1,795	1,123	969
Small Saltwater Fish	327	324	389	697	1,078	1,321	1,216	1,078	757	583	449	373
VSmall Saltwater Fish	118	106	134	360	618	737	672	552	426	361	226	157
Large Freshwater Fish	951	791	733	697	707	703	703	707	738	776	838	951
Medium Freshwater Fish	235	212	200	246	273	358	340	328	283	261	254	258
Small Freshwater Fish	60	51	57	118	184	217	196	184	132	106	88	74
VSmall Freshwater Fish	13	12	14	37	64	76	70	57	44	38	24	17
White-tailed Deer	1,804	1,804	1,804	1,754	1,734	1,866	2,292	2,573	2,656	2,453	2,170	1,883
Black Bear	32	35	36	36	36	43	49	54	55	50	42	38
Alligator	430	430	539	639	639	539	430	394	421	420	394	394
Wild Turkey	123	125	145	184	254	309	268	195	167	145	140	128
Raccoon	157	157	157	148	162	190	214	258	243	214	198	177
Opposum	39	34	67	56	51	45	39	34	67	56	51	45
Rabbits	98	90	82	78	142	135	123	87	107	99	80	67
Squirrels	41	46	43	47	44	46	46	53	53	48	46	44
Upland Birds	8	11	14	18	34	55	60	54	37	26	18	12

Waterfowl	173	137	106	80	58	61	86	114	145	178	217	214
Wading Birds	45	45	66	93	124	153	187	184	147	115	88	64
Sea Turtles	17	24	156	481	1,089	2,065	2,065	1,089	481	156	24	17
Freshwater Turtles	390	390	390	390	390	395	399	412	416	408	403	395
Reptiles	33	33	33	33	33	33	38	48	58	53	48	38
Amphibians	63	52	45	45	45	45	45	45	100	119	119	82
Shellfish	4,003	4,003	4,403	4,804	5,604	6,405	7,206	8,006	8,006	6,805	5,204	4,403
Sea Turtle Eggs	0	0	0	0	0	985	1,477	1,642	1,313	821	328	0
Maize	0	0	0	0	0	0	0	22,684	28,355	14,178	0	0
Beans	0	0	0	0	0	0	0	9,252	11,564	6,939	0	0
Squash	0	0	0	0	0	0	0	1,668	6,672	8,340	4,170	0
Amaranth	0	0	0	0	0	1,904	7,616	9,520	9,520	4,760	0	0
Sunflower	0	0	0	0	0	979	3,915	4,894	4,894	2,447	0	0
Maygrass	0	0	0	0	732	1,829	1,829	1,098	366	0	0	0
Sumpweed	0	0	0	0	436	1,089	1,089	653	218	0	0	0
Acorns	0	0	0	0	0	0	3,037	5,467	6,075	4,252	0	0
Hickory Nuts	0	0	0	0	0	0	7,531	13,555	15,062	10,543	0	0
Cattail/Bullrush	0	0	1,746	4,075	5,821	5,821	4,657	3,493	2,328	1,164	0	0
Chenopods	0	0	0	433	1,011	1,444	1,444	1,156	722	289	0	0

earlier or were projected as reasonable quantitative estimates where no specific data or only qualitative data were available. It should be noted that the framework of this GIS model is not dependent upon the initial values chosen, and inserting better or alternate data is always possible when they become available.

The analysis of these variables allows a projection of the expected number of calories per 30 m map unit of prime habitat (HM value of 1), as well as their monthly resilience (a function of the estimated population density, their rate of survival assuming a stable population, the length of time it takes for an individual to reach reproductive maturity, and their mean number of offspring). Table 2 illustrates the maximum calculated available calories by forage category and month, assuming climatic conditions similar to today and a stable (modern) sea level since 4500 B.P. The caloric values were then multiplied by each of the appropriate HM surfaces. The result is the transformation of each of the 444 surfaces into an expression of the ACM. Figure 3 provides one example of an ACM surface.

The ACM is, in essence, a representation of the exploitable ecological landscape by species and month. If we consider the percentage that each forage category contributes to the diet, we can actually model the mean historical availability both across temporal periods and through a typical annual cycle. For example, Figure 4 illustrates a dietary model for the Georgia Coast transitioning from the Late Archaic (4500 B.P.) through the Contact Period (300 B.P.) in 100-year increments. It uses all 37 forage categories and is pinned at either end by proportional estimates based on Late Archaic and Contact Period faunal and floral assemblages. The values in between are calculated as exponential or logarithmic percentages of the difference between the end values.

The dietary model is not intended to definitively represent an archaeological interpretation of the range in past diet; rather, it is meant to provide a simulation that can be used to express an overall impression of the transition from Late Archaic to Contact Period diet as we currently understand it. That allows us to use those proportional estimates to weight the expected calories by forage category and month and to combine them into a composite formula. Figure 5 shows a histogram of the annual cycle of available calories for four specific years (B.P.) based on the diet model illustrated in Figure 4, where the total annual caloric contribution of each forage category is consistent with its proportional representation in the diet as a whole but the monthly values reference the immediate availability. Each of these models can be reapplied to the GIS landscape as representations of a composite caloric landscape (two examples are shown in Figures 6 and 7).

Obviously, the histograms illustrated in Figure 5 are idealized representations of the maximum available calories given the assumption of a map unit with the HM value of 1 for all species. Their representation across the real

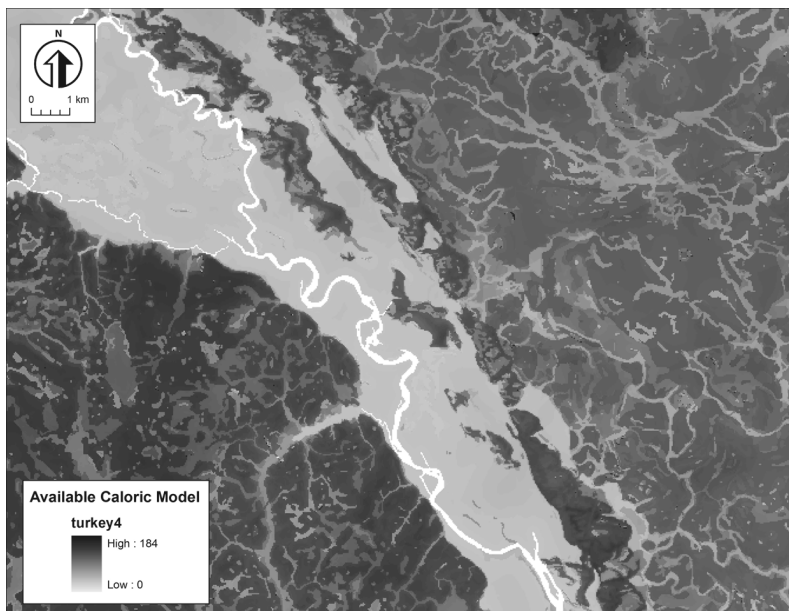


FIGURE 3. *Detail of the Available Caloric Model for wild turkey (April), showing the area near the junction of Wayne, Long, and McIntosh Counties.*

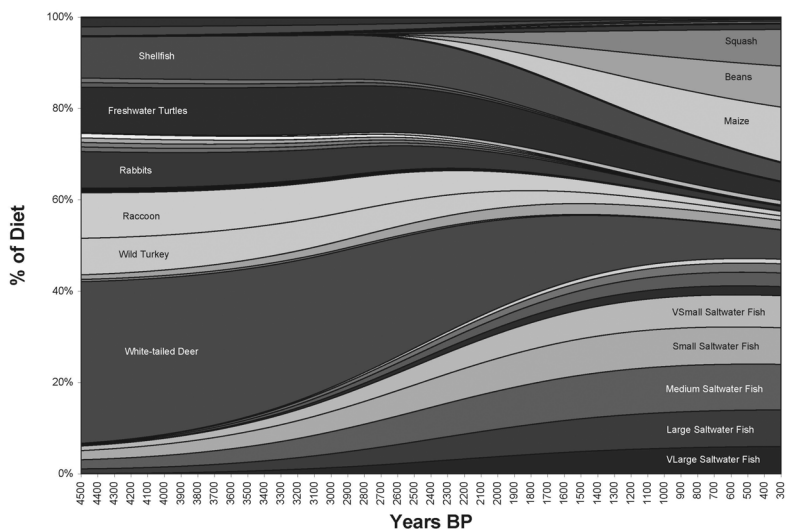


FIGURE 4. *Proportional dietary model for coastal Georgia; only the larger categories are labeled.*

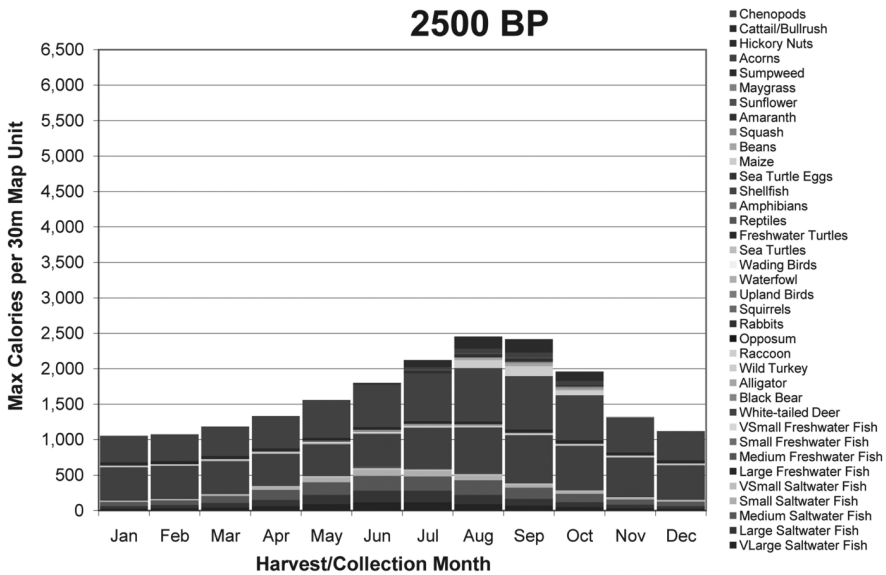
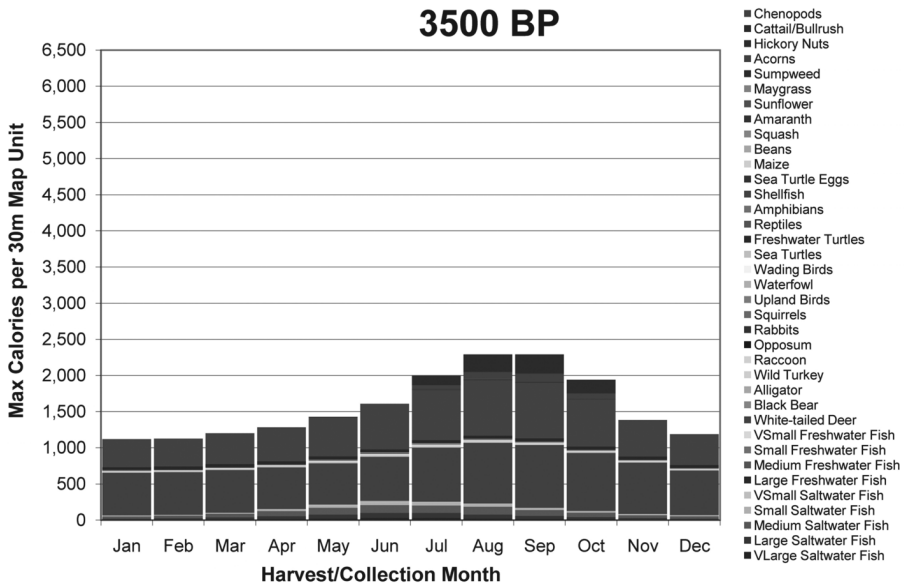
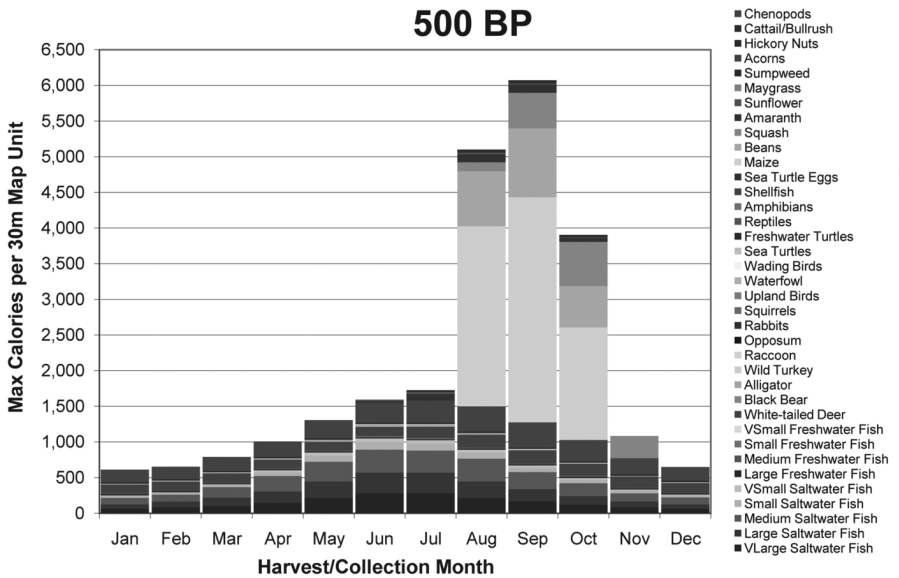
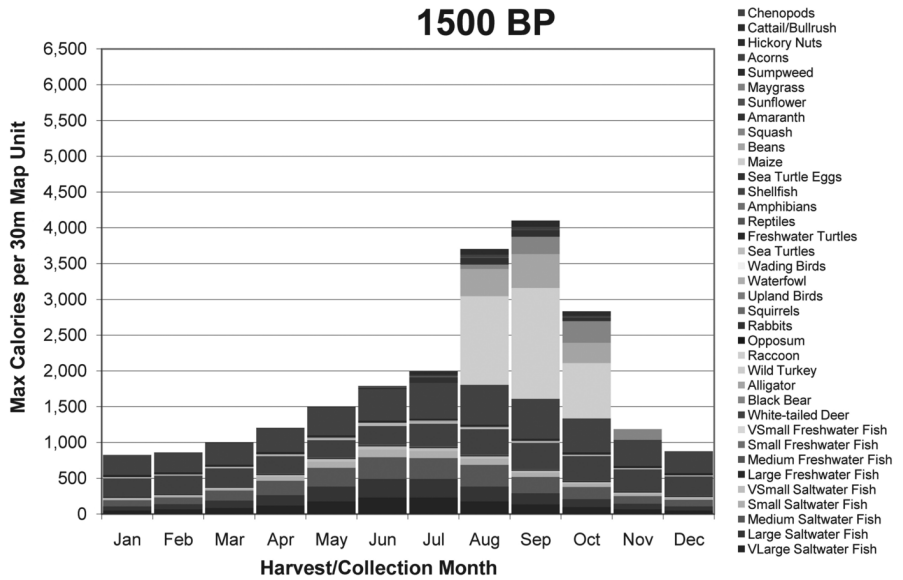


FIGURE 5. (above and facing) Monthly estimates of available calories based on the proportional dietary model, illustrating annual ranges for 3500, 2500, 1500, and 500 B.P.



landscape, as shown in Figures 6 and 7, is going to be more reflective of specific areas or regions with highly variable HM values. However, modeling a dietary composite caloric landscape can help in the construction of targeted predictive models, in other words, identifying the areas that would be most productive or efficient for a given time period and season with all other variables remaining equal (for example, not knowing specific site locations).

INTERPRETING PREHISTORIC ECONOMIES

Available caloric surfaces, though, even when used to help understand dietary contributions, are somewhat limited. To be useful in helping us understand the economics of specific sites and regions, they need to be transformed into a model for “returned” calories—those calories that were actually consumed and the extraction of which historically affected both human subsistence and ecological resilience. To do this, a third model (the Returned Caloric Model) was created on the basis of our understanding of the costs of acquiring, processing, and storing calories. In general, we can assume that proximity and technological innovation are the primary means by which such costs are reduced. Thomas (2008) provides a very detailed discussion of processing time and calories consumed for most of these forage categories on the Georgia Coast during the Late Prehistoric, and his proportional return values (as expressions of calories per hour of effort) were assumed as a baseline, with modifications for earlier time periods where somewhat inferior methods may have been employed in resource acquisition success or processing (particularly for harvested plant species). This portion of the analysis is still in progress, but some example applications can be illustrated.

Given an assumption of a single day’s foraging, the rate of caloric return on any forage category was calculated by subtracting the caloric effort expended from that which would be expected to result from eight hours of activity acquiring or processing it. For some species, the return is recognized almost immediately (for example, shellfish are harvested and generally eaten quickly), while for others there may be long periods of planting, tending, and harvesting before the returns are realized (for example, maize agriculture). The returned calories can also be consumed quickly (before spoilage) or harvested in quantity, stored, and released gradually over time. This is especially the case for low-moisture grains but can be considered for other species as well. The RCM involves the multiplication of each ACM value by the predicted percentage of return for the forage category for that time frame; there is currently no assumption of seasonal or monthly changes in the rate of return based upon technological or processing techniques. The variations in the HM and ACM already account for seasonal changes in hunting success, harvestability, or the yield in meat weight.

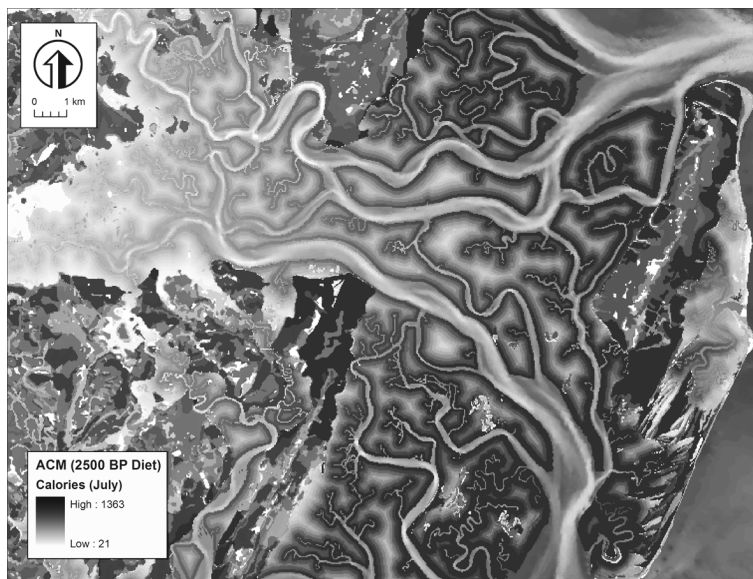


FIGURE 6. *Detail of the composite caloric landscape based on the 2500 B.P. dietary projection, showing the area of the North and South Newport Rivers.*

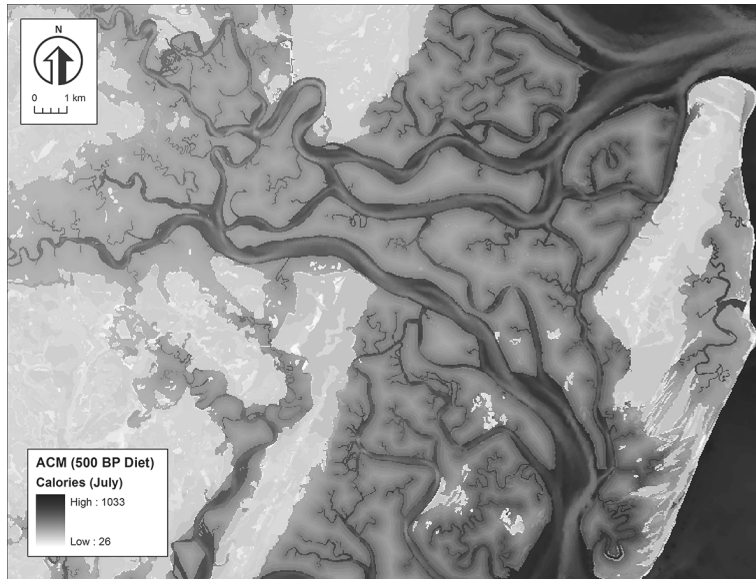


FIGURE 7. *Detail of the composite caloric landscape based on the 500 B.P. dietary projection, showing the area of the North and South Newport Rivers.*

Interpreting the RCM brings up several additional considerations. First, caloric returns have a natural tendency to “fall off” spatially from a central point. The cost of acquiring calories includes a travel cost to go from one’s location to the place at which the calories are gathered and then back to the location of processing, consumption, and/or storage. This is a basic underlying assumption of both OFT and CPF. Those calories that are most easily acquired and consumed are those that are closest at hand. To address this in the Coastal Georgia study, two friction surfaces were created: foot travel and canoe travel. Each basic map unit in the study area exists as a 30 m pixel that can be given a value based on the cost of crossing it. In highly dissected areas, travel friction would be a function primarily of slope and vegetation density. Because of the lack of terrain slope in Coastal Georgia, travel costs are instead a function of vegetation density, water depth, the strengths of tidal, river, and ocean currents, and the firmness of the substrate.

Each of these constraints was modeled from the baseline variables employed in the HM in such a way that it was possible to estimate the number of calories that would be consumed (by one person carrying a load of less than 40 kg) to cross any given map unit in the study area by foot and by canoe. The range included a minimal cost of 2 kcal for crossing an open 30 m map unit unimpeded by vegetation on foot and of 1 kcal for covering the same unit by canoe over open slack water. The upper limits reached 20 kcal for swimming across 30 m of deep tidal water or for portaging a small canoe through relatively dense vegetation. Calories burned in this way were estimated from several online calorie counters using average male adult size and weight characteristics.

From any given point, the accumulated calories over distance (the cost-distance) by either foot or canoe travel is a representation of the falloff of returned calories (for example, Figure 8). For example, if one collected a deer within 120 m of home, it would represent an expenditure of at least 16 kcal for one person to travel to that location and carry the processed deer back. If that same deer were collected at 5 km away from the home site, it would have required more time traveling between the kill/processing point and the point of departure. The investment at 5 km would have been at least 667 kcal, more if the terrain was difficult, sloping, or obstructed by vegetation. That expense is subtracted from the potential caloric return and would represent a loss to individual or family consumption, trade, and even time spent doing other tasks.

Given that some species provide only a modest number of calories whereas others provide many more, the cost-distance (foraging radius) at which it is no longer efficient to collect a given species varies according to its probable caloric return, ability to be gathered in quantity, dietary attractiveness, and potential for other uses and on the current caloric or nutritional stress of the foragers. Similarly, the cost-distance radius at which it is more efficient to process the collected resource rather than bring it back whole (processing radius) is also

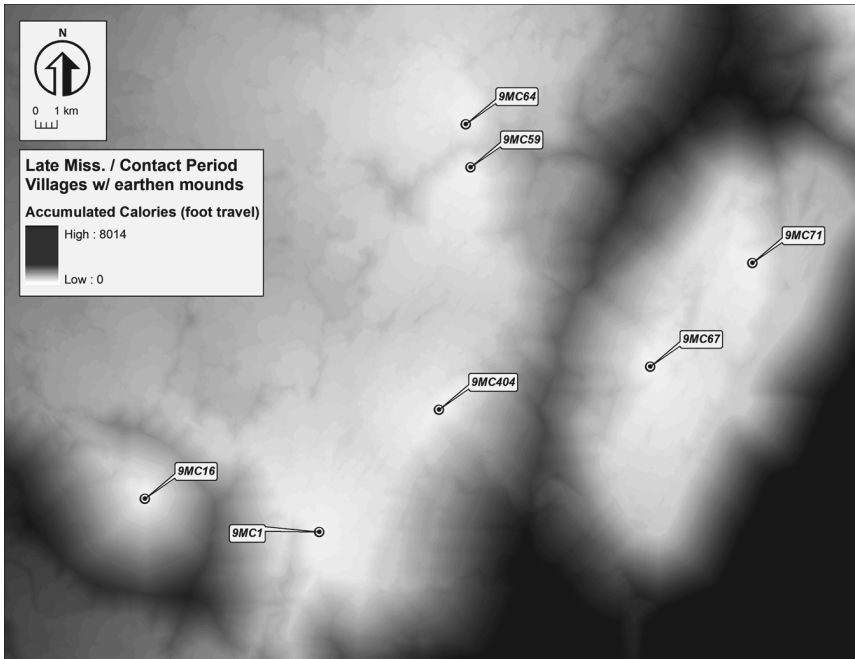


FIGURE 8. Detail of the foot-travel caloric distance (cost-distance) from several known Late Mississippian/Contact Period villages with earthen mounds, showing the area across from Sapelo Island.

a function of the species' weight and its processing time or difficulty. Thomas (2008) provides a very detailed discussion of the probable foraging and processing radii for many species or forage categories in the Coastal Georgia region. In general, he finds that for most species an effective one-way daily foraging radius of 450 kcal consumed (or around 5 km in his estimation) is likely (Thomas 2008: Figure 11.12). He also charts processing radii as a function of distance and categorical thresholds (Thomas 2008: Table 10.7).

For the Coastal Georgia analysis, caloric distances were calculated from known archaeological locations in the study area (based on 2010 information from the Georgia State Site Files) for both foot and canoe travel. The resulting surfaces can be used in several different ways. First, foraging and processing thresholds can be generated for any species of interest. For example, the processing radii provided by Thomas (2008: Table 10.7) can actually be mapped as buffers around a central place; indicating the point beyond which it is more efficient to process the resource before bringing it back. This helps illuminate areas where we would expect to find processing sites related to central place occupations. This is particularly pertinent with regard to shellfish processing vs. consumption.

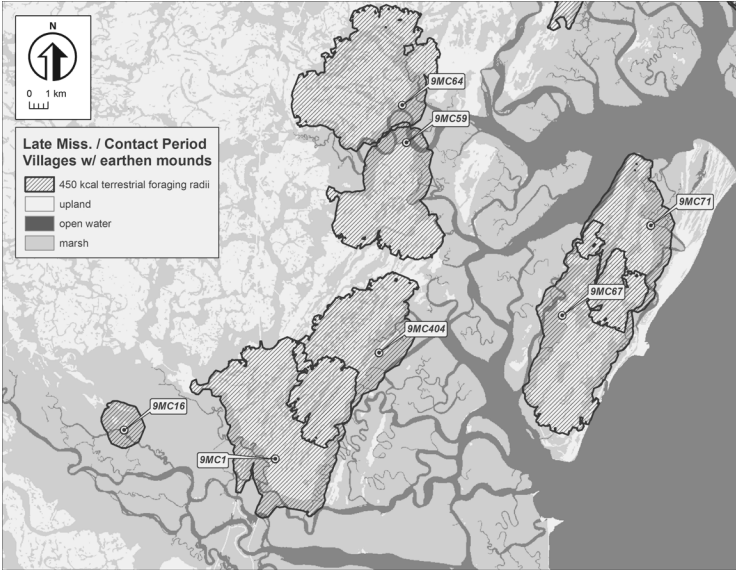


FIGURE 9. Detail of the terrestrial foraging buffers around several known Late Mississippian/Contact Period villages with earthen mounds, showing the area across from Sapelo Island.

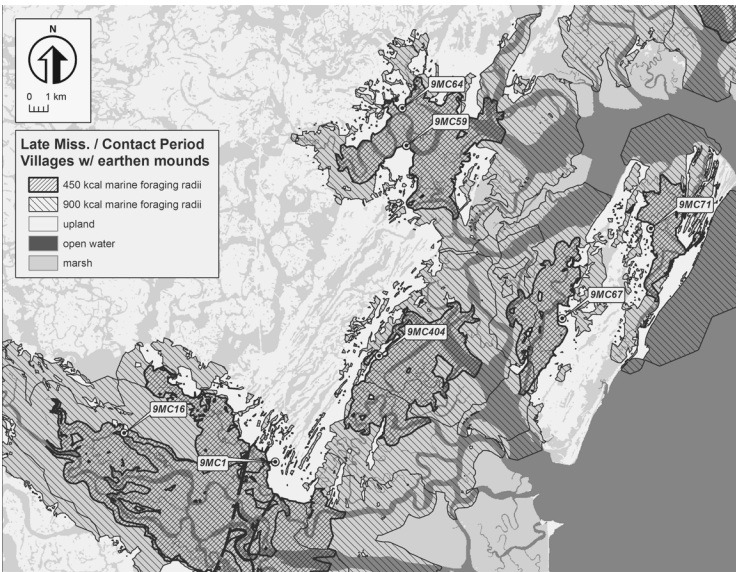
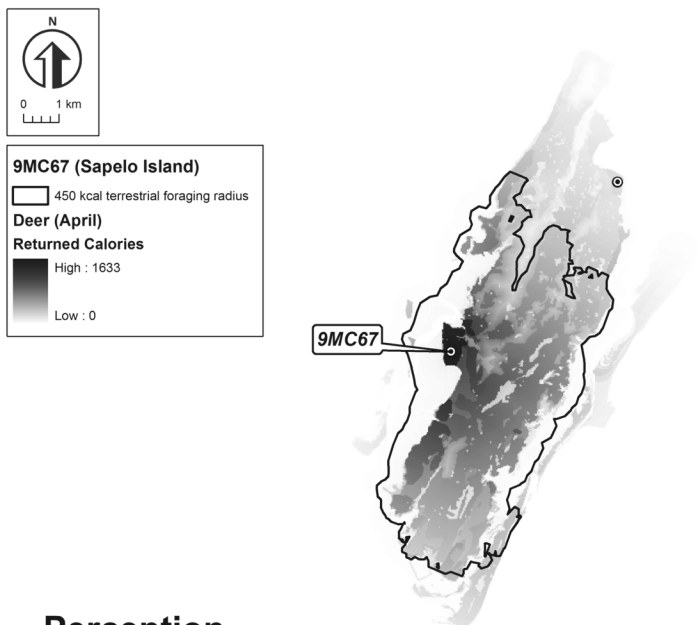


FIGURE 10. Detail of the marine foraging buffers around several known Late Mississippian/Contact Period villages with earthen mounds, showing the area across from Sapelo Island.

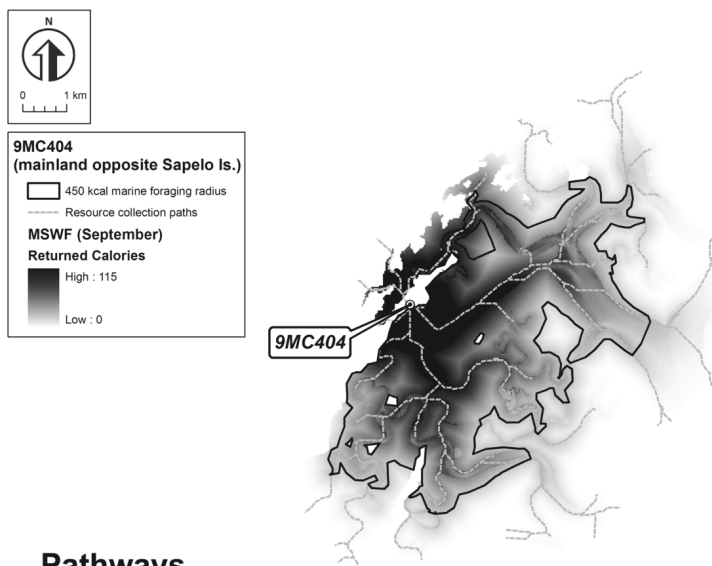
Assuming an average effective daily foraging radius of 450 kcal, the “catchment areas” around any given site can be mapped (based on foot and canoe travel—that is, terrestrial and marine foraging respectively—Figures 9 and 10) and the mean and total caloric returns can be calculated for any given month for any one species, or for weighted combinations that represent projections of complete diets. This could be used to estimate carrying capacities and site populations, as well as help understand how they might change seasonally. Modifications of those radii include consideration of multiple person canoes (which would extend effective foraging areas), as well as gender and age specific foraging tasks (which may look very different given the focus they would have on different species).

Additionally, we need to consider that the success of any foraging activity is a function of perception and terrain familiarity. The cognitive map employed by the forager to help her or him collect a given resource is going to be most complete and accurate in areas which the forager most commonly frequents. Even though we may have a fairly complete and accurate GIS model of the terrain for many miles around the site, the prehistoric individuals living there have only the cognitive perception of their daily terrestrial and marine foraging areas and perhaps some distance outward. The accuracy of that perception diminishes at greater distances from their central place. As a result, there should be a corresponding decrease in foraging success as the forager transitions from the immediate familiarity of using repeatedly successful locations to making decisions “on the fly” with regard to unfamiliar terrain. This particular kind of falloff in caloric returns is probably most notable with fishing, where the underwater (and hence not visible) terrain has a great effect on the success of foraging. Successful fishing spots are recognized only over a long period of repeated use.

Because these models are ultimately representations of the spatial distribution of potential energy sources, it is may be possible to develop a wide range of interpretive surfaces that consider more complex economic issues (a few examples are illustrated in Figure 11). The foraging radii (including both proximity and perception-related falloff rates) can provide estimates of carrying capacity, relative monthly bounties by forage categories, intensity of resource competition, and surplus and exchange potential. Transforming the accumulated caloric distances into pseudo-topographic surfaces can help model and understand the success of resource acquisition pathways (for example, by performing pseudo-hydrologic or least-cost path analyses). Caloric distance can also function as a proxy representation of territories (using caloric thresholds—“calorie-sheds”—as boundaries) or social dominance (larger population centers may occupy a visible “caloric sink” and might extract calories from adjacent areas through controlling exchange routes or tribute).

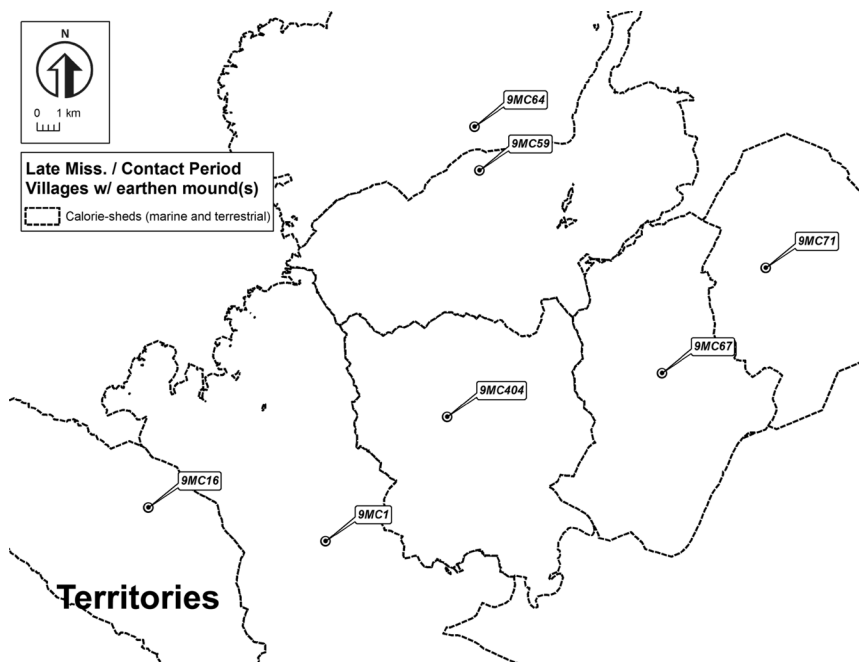
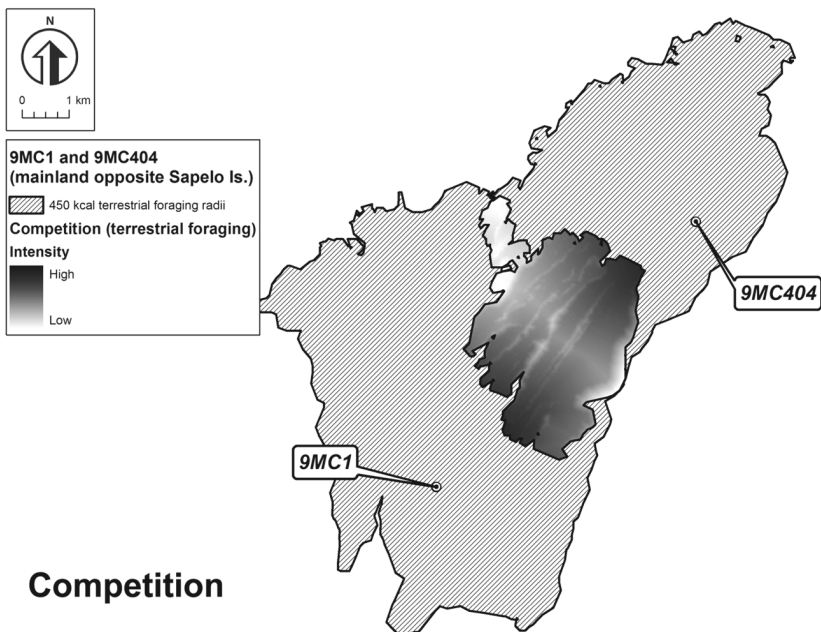


Perception



Pathways

FIGURE 11. (above and facing) Some examples of more complex interpretive surfaces using the Coastal Georgia data, showing various locations.



When we examine the long sequence of occupation at a single site or set of sites, reflexively feeding in the species resilience to the caloric falloff rates can increase our insight into regional historical ecologies and help us to understand how sustainability may have declined under different climatic and social conditions. Obviously this is a contextual interpretive issue based on understanding the details of a specific site or set of sites beyond the information provided from the Georgia Archaeological Site Files. But it is an avenue of research that remains to be pursued. Ultimately, if we consider that spatially modeling the prediction, manipulation, harvest, exchange, and storage of fundamental caloric elements is a useful way of understanding historical ecologies as well as prehistoric economies, the insights we take away can be applied to our modern settings and can be used to examine our own impacts on ecological resilience and sustainability. Our modern economies may seem to be distantly removed from the environment with their focus on currency and stock exchanges, large-scale manufacturing, technological research, and worldwide transportation networks, but everything we do as individuals, families, communities, and nations is rooted in our ability to manage our caloric intake. Every dollar spent around the world for any transaction ultimately finds its way to being traded for calories. And calories still come only from other organisms that have to be planned, predicted, managed, harvested, processed, transported, exchanged, and consumed.

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Feeding History

Deltaic Resilience, Inherited Practice, and Millennial-Scale Sustainability in an Urbanized Landscape

The landscape of southern Iraq is a palimpsest of modern and ancient features representing overt attempts to modify the “natural” fluvial regime, incremental changes accruing to long-term subsistence strategies, and events triggered by the interaction of geomorphologic forces with these anthropogenic changes. As such, it presents a landscape heritage uniquely suited for multimillennial-scale examination of sustainable anthropogenic practices. Using multiscale settlement surveys, remote sensing data, paleoenvironmental proxies, and historical (cuneiform) texts, this essay models grain-cultivation practices from the third millennium B.C.E. in three subzones of this deltaic setting in an effort to determine the likely productivity of this agricultural scheme, signatures indicative of human agency in creating and maintaining this ecological niche, and the continuity and sustainability of these practices through space and time (Figure 1).

As modern societies seek to understand their past, present, and future relationship to the natural environment, human impacts on environmental and agricultural sustainability and the relationship of those impacts to urban resilience have returned to the forefront (Costanza, Graumlich, and Steffen 2007; Hassan 2008). A concept first developed in biological and ecological studies, sustainability is described as the ability of a system to remain diverse and productive over a long period of time, while resilience can be described as the ability of a system to cope with and adapt to change (Redman 2005; Laland and Brown 2006). When applied to human communities, these terms refer to long-term and multiscale human modification of the landscape, especially as related to the extraction of natural resources. “Long-term” is, of course, a subjective measure, ranging from the multicentennial province of historical ecology (Crumley et al. 1994), to multimillennial scale studies conducted by landscape archaeologists (Adams 1981; Wilkinson 2003; Wilkinson et al. 2007; Kohler 1992; Kirch et al. 2007).

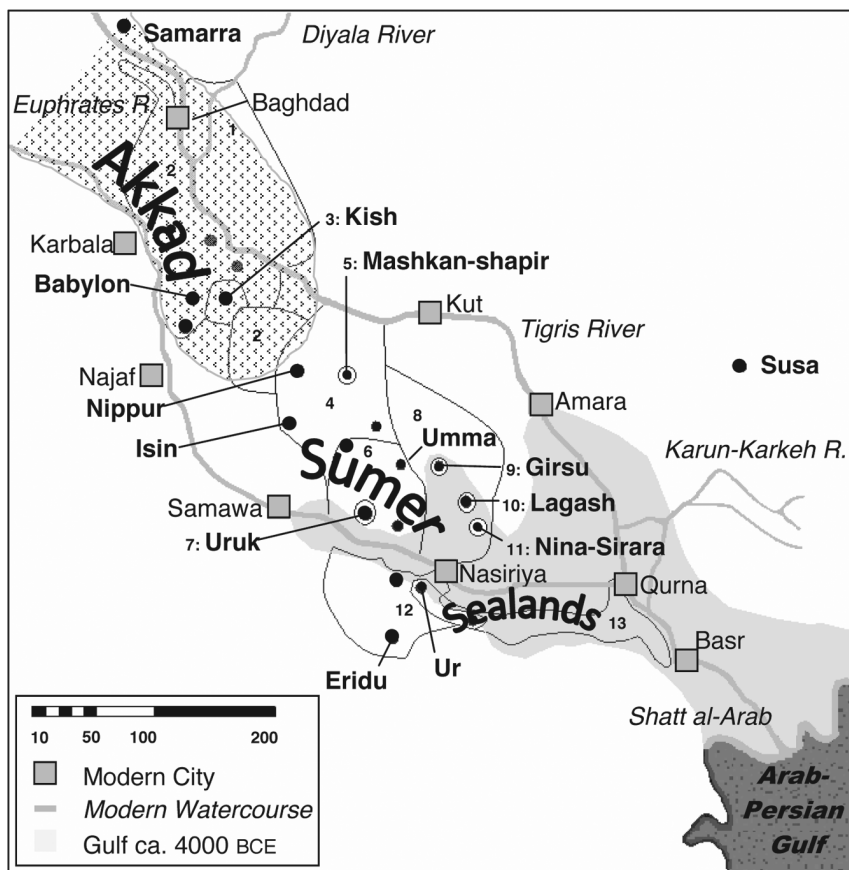


FIGURE 1. Major archaeological sites of alluvial Mesopotamia, with surveyed areas and hypothetical extent of the Persian Gulf ca. 4000 B.C.E.

1. Diyala Survey. 2. Akkad Survey. 3. Kish Survey. 4. Nippur Survey.
 5. Mashkan-Shapir. 6. Warka (Uruk) Survey. 7. Uruk. 8. East Gharraf area,
 with: 9. Tello (Girsu), 10. Senkereh (Lagash), and 11. Zurghal (Nina-Sirara).
 12. Ur-Eridu Survey. 13. Hammar Lake Survey.

Among potential loci for such “long-term” studies, the surviving cultural landscape of southern Mesopotamia provides an unparalleled diachronic data set—both historical and archaeological—for investigating the role of millennial-scale cycles of sustainability, resilience, and resource maximization related to the rise of complex societies (Adams 1960). Home to large towns and cities for perhaps 8,000 years, the modern Iraqi landscape comprises a palimpsest of ancient and modern features. This palimpsest reflects periods of overt human attempts to modify the “natural” fluvial regime, incremental changes

nested within long-term agricultural extensification and intensification strategies, and responses to events triggered by the interaction of geomorphic forces and these anthropogenic changes (Wilkinson 2003).

The most visible features of the ancient landscape are archaeological tells (mounded sites, resulting from multiple reconstructions on top of previous foundations), abandoned channels and canals, and ancient field systems preserved both across now-desert areas and within modern agricultural systems. Reconstructing the impact of human decision making on the rise and stability of societies as well as long-term trends of resilience in this landscape requires the integration of geological, paleoenvironmental, archaeological, and textual evidence. Each of these data sets provides only snapshots of cycles of human-environment interaction, but, taken together, they allow us to begin to investigate (and model) the impact of human decision making, resilience, inherited practice, and sustainability in the evolution of the ancient Mesopotamian urban landscape (Wilkinson et al. 2007).

By integrating the praxis-driven methods of historical ecology, anthropological archaeology is well suited to map evidence of the broad impacts of long-term activities preserved in the material record of the past. As anthropologists, we recognize that understanding changing patterns of human behavior within dynamic environments is central to our understanding of the development of complex societies. As archaeologists, we find ourselves with unique lines of evidence that can be used to elucidate the processes of landscape exploitation and resource resilience. Methodologically, this essay draws on cuneiform texts (Liverani 1996; Steinkeller 1987, 2001; Englund 1990; Heimpel 2010), settlement survey,¹ remote sensing data (Hritz 2005, 2010; Pournelle 2003b, 2007), ethnography and ethnoarchaeology (Table 1),² and geomorphological studies,³ as well as on paleoenvironmental samples and proxies,⁴ to identify verifiable signatures of past subsistence practices in the Tigris-Euphrates-Karun delta in an effort to assess the role of niche construction in the genesis and evolution of the world's oldest-known urbanized landscape.

Niche construction is the process whereby organisms (including humans), through their activities and choices, not only adapt to their environments but also construct them (Odling-Smee, Laland, and Feldman 2003). Many natural-selection pressures to which organisms are exposed exist in part or solely because of prior niche-constructing activities (Laland and Brown 2006). This is perhaps nowhere more evident than in the coupling of agricultural in- and extensification with urban construction and growth, a set of activities that can have such profound impact on factors such as afforestation, soil and pedosol formation, surface and ground water hydrology, and local microclimates as to render agricultural practices predicated on a specific set of environmental conditions obsolete within a generation (Wilkinson 2003). Niche construction

TABLE 1. Twentieth-century Geographies, Ethnographies, and Travelogues Treating the Wetlands of Southern Iraq

Author	Date	Region	Environ's	Major Crops, Products
UK NIID	1944	All	Basra, Maqil	Nomads, fish, dates, barley, wheat, rice
Wirth	1962	Euphrates Tigris Gharraf al-Arab	Diwaniya, Rumaitha Amara Hai Zubair	Palm gardens, rice Rice, winter wheat Barley Dates, vegetables
Al Barazi	1960	Mid-Euphrates	Karbala-Diwaniyah	Grain
Fernea	1965	Mid-Euphrates	Diwaniya (el-Nahra)	Rice
RAF	1916	North Tigris-Gharraf	Kut	Reed; winter pasture
Ochsenschlager	1993	Lower Gharraf	Shatra (al-Hiba)	Sheep, carpets, fish, barley
Hedgecock	1927	Upper East Tigris	Amara-Qalat Salih (Musaïda)	Rice, water buffalo
Maxwell	1957	Upper East Tigris	Amara-Qalat Salih (Turaba)	Water buffalo
Thesiger	1964	Tigris-Euphrates delta, esp. West Tigris	Amara (Qabab)-Saigal-Nasiriya (Ech-Chubayish)-Qurna (Howair); smaller villages in deep marsh	Buffalo, cattle, sheep, reed, mats, rice, fish, fowl, pelts, pigs
Westphal-Hellbusch & Westphal	1962	Tigris, especially West Lower Tigris-Euphrates	Amara-Saigal-Qurna (Birriz)	Cattle, reed, mats, buffalo, yarn, rice, fish, pelts Palm gardens, reed, buffalo, rice
Salim	1962	Lower Euphrates	Ech-Chubayish	Reeds, mats, salt, fish, millet, cattle

includes all cases of niche modification that modify the experienced environment—not only through perturbation (as by deforestation or plowing) but also by regulating structures to mitigate variability in environmental conditions and through relocation in space by dispersal, migration, and habitat selection. In drawing attention to active agency as a source of ecological and evolutionary change, the concept of niche construction holds great potential as an explanatory framework for archaeology but remains underexplored (Laland and O'Brien 2010).

Using GIS integration of past ground survey, multiperiod satellite images, newly available Digital Elevation Models (DEMs), and historical texts, in this essay we begin to map signatures of cultural landscape variability that represent human attempts to create sustainable agricultural niches—preserved as relict channels, canals, fields, and archaeological sites—recorded over the course of several millennia in southern Mesopotamia. We propose that the resilience of this landscape—its ability to sustain the interaction of cycles of exploitation, conservation, release, and reorganization in ways that promote long-term, successful human survival (Redman 2005: 73)—is reflected in a flexible and varied structure of interconnected agro-pastoral niches created, regulated, and re-created through space and time.

GEOGRAPHY AND LANDSCAPE

Geographically, southern Mesopotamia comprises the flat alluvial plains located between the Tigris and Euphrates Rivers in modern-day southern Iraq. Baghdad in the north; the shoreline of the Arab-Persian Gulf in the south; the Arabian desert in the west; and the Zagros Mountain foothills in the east bound this semiarid basin (Figure 1). In general, seasonal rainfall across the alluvial plains totals less than the 200 mm annual minimum required for rain-fed agriculture. In addition to this dearth of rainfall, the rains in Iraq are characterized by interannual variability in both timing and amount. Decadal rainfall totals recorded by weather stations in Baghdad and Mosul reveal that most of the rain occurs in downpours over a short period of time during the winter months (Buringh 1960: 44). The timing, amount, and variation in rainfall cycles make rain-fed agriculture impossible, and present-day cultivation of these vast plains requires artificial irrigation.

Both underlying geology and the action of the dynamic rivers shape the topography of southern Iraq. The plain is a tilted basin (geosyncline) composed of the accumulated soils and sediments eroded and brought down by the rivers and their tributaries from the uplands of Iran, Syria, and Turkey. The continual sedimentation in this relatively flat basin results in the visual appearance of little topographic change within its 444,442 km² area. However, there is a

gentle change of 1:10,000–1:15,000 gradient along the plains, amounting over the course of 445 km from Baghdad in the north to Basra in the south to a drop in elevation of 30 m. This change, though slight, results in microtopographic differences across the alluvium, closely related to alluvial hydrology (Buringh 1960: 35; Jassim and Goff 2006).

Thus, despite the visual flatness and the overall climatic homogeneity of the alluvium, the plains are characterized by heterogeneity of microenvironments, resulting from the interaction of the dominant riverine systems with the natural microtopography of the plain. The Euphrates and Tigris Rivers enter Iraq from Syria and Turkey, respectively, and have different morphological characteristics. Once entering the alluvium at the town of Hit, the Euphrates River splits and rejoins in multiple, anastomosing branches over its 750 km course, eventually reaching the Tigris near Qurna to form the Shatt al-Arab waterway. Euphrates channels are characterized by their levees, created by the cumulative action of soil deposition alongside a channel following each annual inundation. Over time, this process of soil deposition creates a wide soil ridge, elevated above plain level, with the channel of the river running along its crest. Soils deposited during levee formation are most agriculturally productive toward the top of the levee and decrease in agricultural potential down slope (Postgate 1994: 174).

As it makes its way along the eastern flank of the alluvium to Amara, where it finally splays into three levee-building channels, the Tigris River exhibits a different channel morphology. As it enters Iraq, it incises itself into the plain as a single stream, rather than building up a levee. Drawing irrigation water from this deep channel requires water-lifting technology, evidence for which first appears late in the first millennium B.C.E. At that time, the Tigris was located in or near its modern course. As a result of the combination of this spatial location (perceived as both ancient and distant from early cities and their agricultural hinterlands in the central alluvium) and the challenge to its use, earlier scholars posited a long-lasting agricultural irrigation system that relied heavily on the Euphrates—a supposition that recently has been challenged both on textual grounds and by remote sensing studies (for example, Steinkeller 2001; Pournelle 2003b: 169; Hritz 2005, 2010).

The interaction of the rivers, the plain topography, and human modifications of this landscape for subsistence extraction result in diverse alluvial microenvironments, but, in general, three broad landscape zones can be described. The northern part of the alluvium, with relatively flat topography and eastern-trending drainage, is characterized by broad tracts of irrigated agricultural land. The central alluvium is characterized by intertwined and abutting palm swamps, seasonal marshes, tilled agricultural lands, steppe-pasture, and

silt-dune fields. The far southeast of southern Iraq comprised the once vast (now largely drained and fragmented) fresh- and salt-water marshes, lagoons, and estuaries of the combined Euphrates-Tigris-Karun delta. Within these three zones, the human-modified agricultural landscape has both common basic features—natural, artificial, and hybrid channels and canals; levees; archaeological tells representing long-term habitation in one location; tracts of arid and fallow grazing land; and flood basins—and key variations, which we will describe.

KEY DATA SETS

There are several key data sets that can be used to reconstruct the ancient subsistence landscape of southern Mesopotamia. The majority of archaeological settlement survey data for the region was collected by Robert McC. Adams, with contributions from his students and colleagues (Adams 1965, 1972, 1981; Adams and Nissen 1972; Wright 1981; Gibson 1972; see Figure 1). Over a period of 30 years, from the 1950s to the 1980s, Adams surveyed roughly one-third of the alluvial plains at varying levels of intensity. He used maps, aerial photographs, and ground walking to identify, locate, map, and date mounded archaeological sites, along with any relict channel levees. He posited associations between settlements and water channels, by period, throughout Mesopotamian history, providing a framework for understanding changes in settlement and channel system structure through time throughout the alluvium.

Another key—and unique—data set is the historical texts, in the form of cuneiform tablets, that provide important and detailed information regarding the diversity in layouts of fields along levees and channels as far back as the end of the third millennium (c. 2100 B.C.E.) The Assyriologist Mario Liverani studied a group of approximately 70 cadastral texts from the time of the Third Dynasty of Ur, known as the Ur III period, plus a handful of texts from earlier and later periods that described field systems across southern Iraq. Specifically, the texts provide information on the length and width of fields, as well as information regarding crop yields, and in them Liverani identified significant differences in field systems between northern and southern parts of the alluvium, despite their apparent overall environmental homogeneity and spatial proximity (Liverani 1996).

Satellite photography and imagery are also key data sets for reconstructing the ancient landscape (Hritz 2005, 2010; Pournelle 2003b, 2007; Parcak 2009; Pournelle and Algaze 2010). The recent release of SRTM⁵ and ASTER⁶ digital elevation models (DEMs) has provided high-resolution topographic data sets without the spatial constraints of the few publicly available topographic map

series. These complementary elevation modeling products make possible a view of the entire topography of the alluvial plains, so that the relationship between microtopographic variation and the features of the cultural landscape are revealed. Modern field systems, roads, and canals contribute to “information overload” that can obscure the visibility of past channels, canals and archaeological sites on satellite images. SRTM provides 90 m resolution, so that, while small, narrow features such as sites or local irrigation canals are not visible, the large, long-lived, kilometers-wide levees of the plain are distinct (Hritz and Wilkinson 2006). Thus, a key advantage of the SRTM data is that they act as a filter for eliminating modern or ephemeral features from analysis.

On the other hand, the ASTER 30 m DEM can be used to fill in some of the detail omitted from the 90 m resolution SRTM. While neither data set provides absolute elevations, the sensitivity of the relative elevations is sufficient to illustrate topography on this flat plain (Figure 2). Thus, SRTM provides the outline and the extent of a relict channel levee and provides a valuable estimate of levee length, width and height, while ASTER reveals the remains of the ancient channel bed and its secondary smaller canals, as well as smaller and more ephemeral features.

Finally, for several reasons, CORONA satellite photographs are particularly useful for identifying relict surface features in southern Mesopotamia. First, the images were collected between 1968 and 1972—that is, at roughly the same time as past archaeological surveys. Therefore, the images record the landscape that was visible to the surveyors at that time, enabling sure correlation between images and survey data. Second, the images capture the landscape prior to the major agricultural and other transforming modernization activities that began during the 1970s. These activities have significantly altered or obscured ancient features. Third, they provide good spatial scale—depending on scanning protocol and technology used, film negatives can be converted to digital images of 1.8m–5m resolution. This is sufficient to identify linear features of barely 1 meter in width or point features as small as individual trees and shrubs. Finally, CORONA is readily accessible as a common data set. Digitized CORONA imagery can be purchased at low cost from the United States Geological Survey.

Integrating these data sets into a geographic information system (GIS) enabled spatial layering of data, reconstruction and association of contemporary ancient landscape features, correlation of these with archaeological and paleoenvironmental data sets, and identification of long-term trends in the cultural and natural landscape. Thus, GIS integration made it possible to address the relationship among microtopography, niche construction, and long-term landscape sustainability in southern Mesopotamia for each of the three key ecological zones.

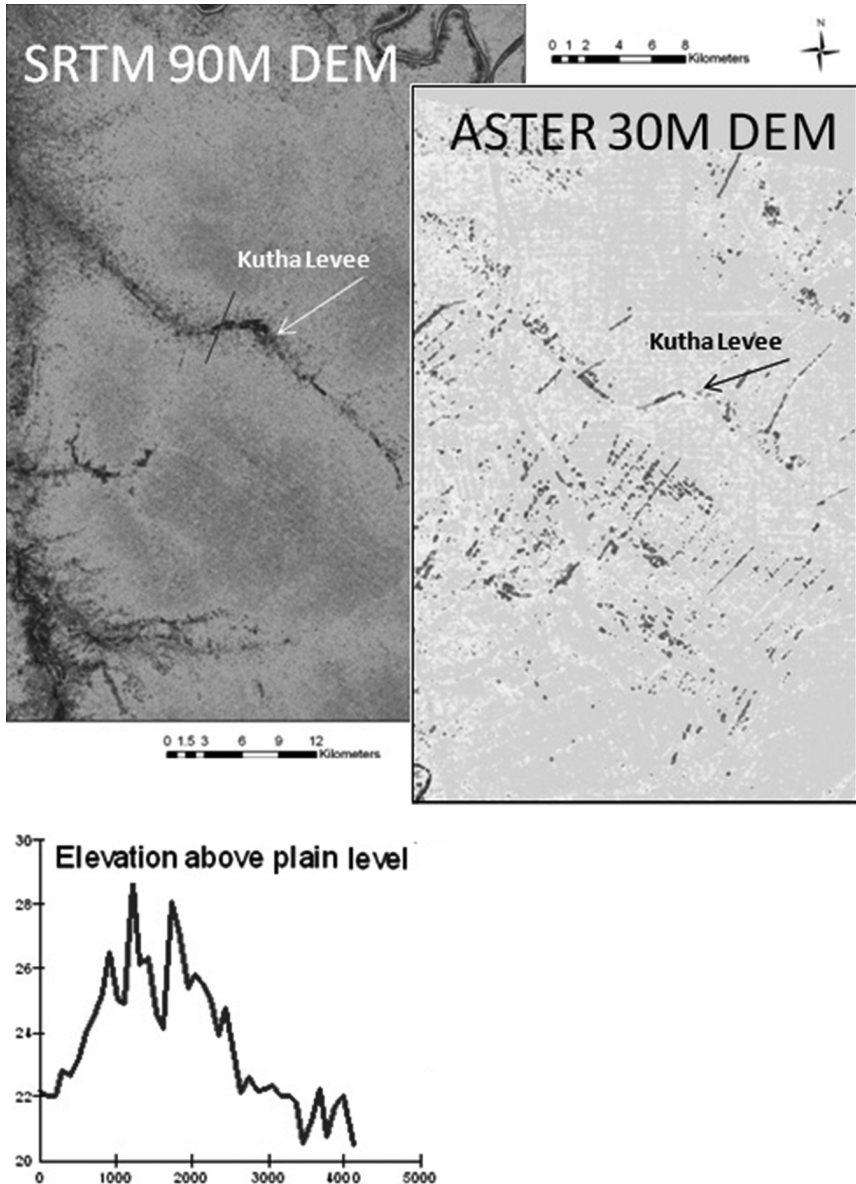


FIGURE 2. Side-by-side DEM comparison of elevation of the relict Kutha levee. The low-resolution 90 m SRTM on the left shows the outline of the ancient levee, and high-resolution 30 m ASTER, courtesy of JPL and on the right, provides small-scale topographic detail such as secondary channels. The generated graph merges data from both DEMs and shows the height and width of the Kutha levee.

MAPPING THE LANDSCAPE

One model agricultural unit of this cultural landscape is that associated with archaeological tells strung along channel levees (manmade or natural). These sites tend to be located near the levee crest, in order to take advantage of the higher-nutrient soils deposited when waterways overtop their banks. Primary agricultural fields are located on the backslope of the levee, with decreasing fertility further downslope. At plain level, the formation of backswamps and gilgai soils is common, resulting from the high natural water table plus poor channel drainage (Buringh 1960: 159). During the Ur III period, gravity-flow irrigation—that is, irrigating by simply creating a breach in the channel levee and allowing gravity to bring water to the lower elevation fields—would have been possible. Throughout the *longue durée* of Mesopotamian history, local environmental diversity has required the creation of specialized subsistence practices for successful community survival. This specialization is visible in the variations in layout and structure of these agricultural units. Evidence for this variation may be found in historical (cuneiform) texts, archaeological survey data, remote sensing data, and microtopographic data. By integrating these records, it is possible to map these locally adapted economic niches and to begin to reconstruct their role in the rise of alluvial complex societies.

AREA 1: THE NORTHERN ALLUVIUM (ANCIENT AKKAD)

With the system of naturally branching channels and canals, the northern part of the alluvial plains, the locus of ancient Akkad, is characterized by intensive cultivation and irrigation. Bounded to the north by Baghdad, to the east by the modern course of the Tigris River, to the west by the Euphrates, and to the south by the ancient city of Kish (Figure 1), the topography of this area, captured on SRTM DEMs and geological maps from the late 1960s (Buringh 1960), is characterized by a 2-meter drop in elevation over the course of the 100 km from Baghdad in the north to Hilla in the south. The western portion of this plain is transited by past and present channels of the Euphrates, running generally from northwest to southeast, and archaeological and textual evidence points to large primary channels of the Euphrates dominating this area throughout antiquity (Gasche and Tanret 1998). Drainage of these channels is guided by the microtopography of the plain. To the southeast, approaching the modern course of the Tigris, elevation dips 3 meters, then slopes upward as it approaches the modern river. As a result, all channels and canals, both natural and artificial, tend to drain in this same direction, and a depression area southwest of Baghdad tends to form a seasonal marshy lake. This area (located, as it is, southeast of modern

Baghdad) has undergone large-scale landscape-transforming activities in the recent past, beginning with the Musseyib land reclamation project of the 1950s and 1960s, but the relatively flat elevation of the western portion of this zone encouraged expansive/extensive cultivation, and field patterns associated with this activity are recorded in archaeological survey, satellite imagery, and historical texts. A brief examination of this area illustrates the complexity of natural and cultural landscape modifications in southern Mesopotamia and the methods by which ancient landscape features can be separated from modern features.

Even at the time the 1960s-era CORONA imagery was acquired, transformation of the Musseyib area for land reclamation and agricultural intensification had begun. New field systems and canals were laid out in even rectangles over relict canal systems (Figure 3). The field patterns of those older systems, preserved in fields that were yet to be intensively cultivated, show a clear difference from the modern system in both layout (not gridded) and orientation (northwest to southeast), and their gridded canals clearly cut through the less-regularized pattern of their predecessors. The new canal systems and fields are oriented northeast to southwest. Thus, it is possible to map the remains of a set of preserved ancient sites and their field systems within the modern landscape from the CORONA images, on which three sites (one large and two small) are embedded within an interlocking canal system. Two canals pass by the edge of the larger sites. Three smaller canals running between the large canals presumably provided field boundaries for each site's immediate agricultural or pastureland. The large site is connected to the smaller surrounding sites by a series of canals. The relict fields from this older system are identifiable by tonal differences that are related to differential retention of moisture in the soils. They also appear within the modern field systems, and the layering of landscape features is clearly visible. The connecting canals are ultimately lost in the modern drainage and field boundaries, illustrating the selective partial removal of ancient features. Since one (but only one) of these sites was dated during the Akkad survey (Adams 1972), we can suggest a date range for this window of landscape of the late third to early fourth millennium B.C.E.

Cuneiform texts from sites in this area describe a similar field pattern throughout antiquity. For example, Liverani (1996) reconstructs fields that are square or contain a variety of square-like shapes, ranging in size from 100 *iku* (35 ha) each. The texts describe extensive and roughly evenly spaced fields taking water from primary or secondary channels of the Euphrates. Drainage canals running parallel served to regulate irrigation water. Overall, the appearance of the agricultural landscape in this area is one of extensive small-field systems. However, in the southeast, this agricultural pattern is different, resulting from microtopographic change and the adjustments to field systems, the product of long-term attempts at local niche construction.

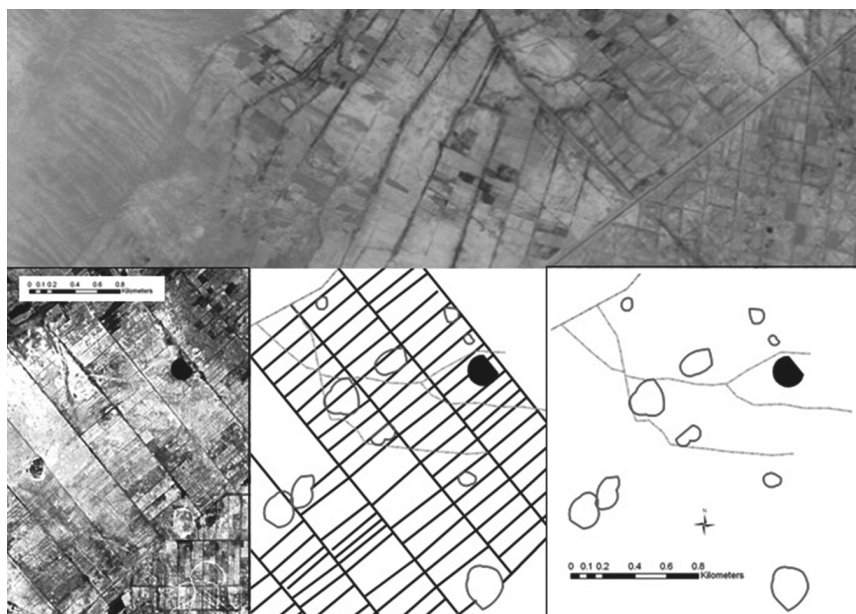


FIGURE 3. Top: A “layered” agricultural landscape: (L) An undated “fishbone” gravity-fed system, now abandoned; (M) a “reactivated” planned irrigation system that relies in part on older canals fed by hydraulic lift; (R) a modern gridded system, dependent upon mechanized field leveling and irrigation pumps. Bottom (L to R): “Removing” layers of the modern landscape to open a window on ancient agricultural systems.

Using the few available 1:25,000 topographic maps for this small geographical area southwest of Baghdad, a team at the University of Ghent traced visible levees (Verhoeven 1998). One of the levees that the team mapped stands out in that it is located at the edge of the lower elevation area in the west, where the field patterns associated with it take on a different appearance. The levee recorded by SRTM and ASTER corresponds in location to the mapped levee, verifying the accuracy of the SRTM data. In addition, using the SRTM data, it was possible to trace this levee system 10 km farther to the south, outside the area covered by the Ghent maps. Topographically, the levee width is preserved on SRTM at just over 4 km, and its height is roughly 4 m above plain level.

By incorporating the SRTM data into a GIS, it was possible to overlay CORONA images. These images provide detail of the features of the levee system that were not visible on the elevation data. For example, the relict channel of the levee, preserved not by elevation but rather as a soil moisture difference, was visible on CORONA images, as were secondary channels and field patterns (Figure 4).

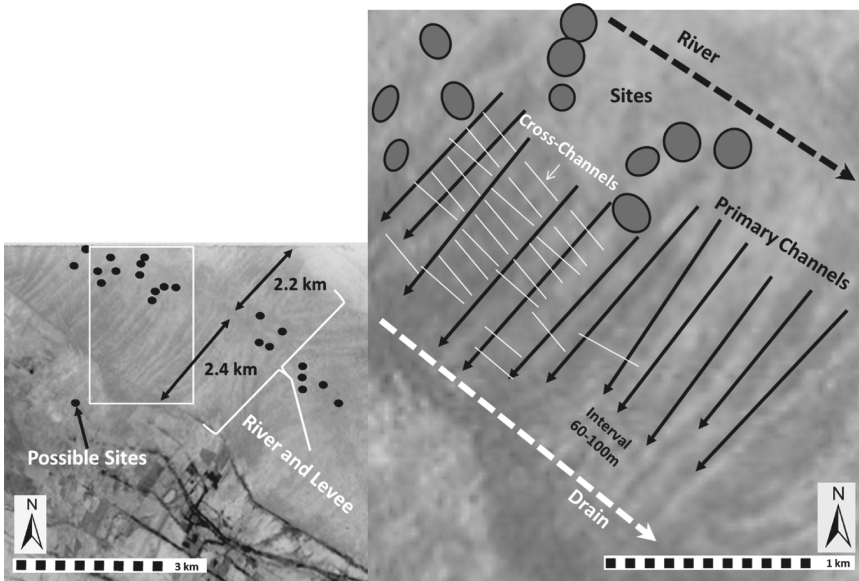


FIGURE 4. CORONA 1968: *the northern alluvium*. (L) Near Mussayib, modern agriculture (top) encroaches on a relict settlement system. Many possible Ur III sites can be identified, associated with a “fishbone” gravity-fed channel system that matches textual descriptions of that era. (R) At maximum resolution, field boundary channels are also visible. Field dimensions match accounting texts (Liverani 1994).

Additional microtopographic data for the area are provided by the Hunting Middle Tigris Soil Survey (MacDonald and Partners 1959). This project systematically augured large areas of the alluvial plain. A small portion of the survey area included the large levee system visible in the SRTM and CORONA images. From these cores, the survey maps provide information on the soils that compose the levee. In general, the soils are riverine and basin soils, with a few instances of stratigraphic layers of shell. The Hunting team also noted roughly 40 archaeological sites on the levee. While the exact count of sites must be taken with caution, because features such as field scatter may have been mistaken for archaeological sites or because low continuous mounds may have been recorded as multiple sites, the maps suggest dense settlement along the channel system.

Thus, by, teasing through multiple data sets, it was possible to disentangle the temporal complexity preserved on the ground in order to reveal the core features of a single contemporaneous (but as yet undated) irrigated agricultural system. In general, this system consists of a large channel preserved at the crest of the levee, which can be traced for 16 km before reaching the area east of Lake

Dalmaj and becoming obscured by modern fields and channels. To the east and west of the main channel are two subsidiary channels that appear to branch off or perhaps avulse from the main channel at its northern end. These two subsidiary branches created smaller-scale levees. They are separated from the main channel by lower elevation basin areas and run a course parallel to that of the main channel for nearly its entire length.

From the main channel it was possible to trace the associated agricultural fields using (primarily) the 1968 CORONA images. Long, narrow offtake channels run from the crest of the main channel down the backslope of the levee on both its eastern and western sides, following the levee gradient. These large primary channels create a “fishbone” pattern on both sides of the main channel, delineating long, narrow fields. The channels can be traced until they terminate in the basin areas off the levee gradient. In some areas, they clearly join a long drainage canal that runs southwest of the levee. The primary channels average 1.3–2 km in length from the levee crest to basin, and each long field contains roughly 35–39 ha of agricultural land. They are located at intervals of from 150 m to 300 m.

The contrast in the structures of ancient agricultural system within this ecological zone indicates the importance of microtopography to the creation of a sustainable agricultural landscape. The extensive, evenly spaced field systems created in the western portion of the area would not have been sustainable in the east, where low elevation and poor drainage would have quickly led to waterlogged soils and salinization. Therefore, the eastern portion of the area required a more spatially intensive rather than an extensive agricultural strategy for successful cultivation of food crops. Overt human attempts to transform this landscape and to enhance the agricultural resilience of these systems are visible in the differences in relict channel and field patterns.

AREA II: SOUTHERN PORTION OF THE ALLUVIUM (ANCIENT SUMER)

Less than 60 km to the south and west, in the heart of the central alluvium, the diversity of microenvironments is even more pronounced. Bounded on the west by the Hillah and Hindiyah branches of the Euphrates, on the east by the Tigris River, on the north by the remnants of the Islamic period Shatt al-Nil, and (until the onset of this millennium) on the south by vast marshes, this area is characterized by natural and cultural landscape diversity. In the west, runoff from two major branches and numerous minor channels of the Euphrates, coupled with human attempts at controlling their waters, creates an environment that tends toward marsh formation. In the central portion of the alluvium, the landscape is characterized by flat fields used for agriculture, interspersed with dune belts composed of soft, wind-borne soils eroded from exposed fields and

relict channels. Over time, cycles of human attempts at agricultural expansion followed by increased wind erosion of the plowed soils have contributed to alternating periods of heavy sedimentation and deflation, with concomitant shifting of dune fields. These interactions of cultural and natural components of the landscape result in diverse and dynamic ecotones.

During intensive archaeological survey, Adams mapped three large Euphrates levees in southern Mesopotamia., located at the juncture between modern agricultural land and desert—an area subject to heavy wind scour, as well as continual use and reuse. He traced these long-lived levees, associated with archaeological sites spanning the third to the first millennium B.C.E., for distances of 60 km or more and found that most of the visible sites dated to the late third millennium B.C.E., the same time period as the texts describing field systems (Figure 5).

Focusing on the central of the three levees and integrating the SRTM and CORONA satellite photography, it was possible to map relict agricultural field patterns. This substantial central feature is preserved at 4 meters above plain

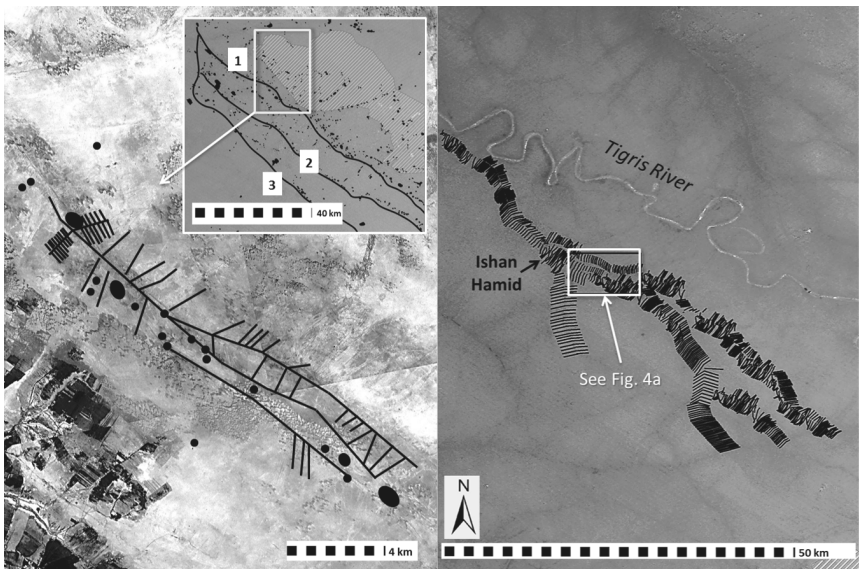


FIGURE 5. *The southern alluvium. (L) CORONA 1968. Ur III sites and major levees mapped from Adams 1981 (inset). Primary agricultural channels mapped from CORONA; secondary field channels modeled from the levee depicted in Figure 4. Field dimensions match those described in local cuneiform texts. (R) SRTM 2000. Major levees appear as darker lines, and a hypothetical field system can be modeled for the entire levee system, based on the detailed mapping described.*

level in height (at its crest) and ranges from 4 to 6 kilometers in width, gradually broadening from north to south. These dimensions are larger than the dimensions of levees in the Akkad area but still correlate closely to the range of dimensions given in cuneiform accounting texts. However, preservation of this levee and its remnant agricultural features is not as clear as in the north. Postabandonment reuse and exposure have eroded some field features, and sedimentation has covered others. Nevertheless, using a combination of those features visible on the CORONA images, the topography illustrated by SRTM and ASTER, and the model outline of features derived from those preserved on the Akkad levee, it was possible to reconstruct plausible ancient field patterns. Long plots of land fit the topography of this levee, with smaller sites from the third millennium B.C.E. spaced at intervals of 2–4 km and larger urban centers at roughly 15 km.

Given the larger size of this levee in comparison to that in the north, it makes sense that channels and canals would be relatively larger as well. Texts describing the agricultural landscape around major southern cities such as Ur and Umma document fields, ranging in size from 100 to 125 *iku* (35–43.5 ha) and occasionally larger (Liverani 1996: 8–12). Rather than mirroring the square shape of fields in Akkad, the majority of those to the south were long narrow strips of land, measuring between 25 and 60 *nindan* (150–360m) wide and about seven times that distance in length—that is, 175–450 *nindan* long (1,050–2,700 m). The river levee would be breached for water offtake, long narrow fields separated by secondary channels would be organized in parallel along this offtake channel, and water flow into secondary channels would be strictly regulated to conserve water and avoid flooding. Furrows plowed along the elongated fields created further subdivisions (Hruška 1985). The water would then be released from secondary channels onto the fields, using the natural gradient of the land and smaller channels. Finally, excess water would flow away into a drainage basin, thus attenuating soil salinization. In such gravity-flow irrigation systems, fields of these sizes would take on the appearance of fishbone landscapes similar to those in the lower-elevation areas of the north.

AREA III: BEYOND THE ALLUVIUM (THE SEALANDS)

Further south, in the lowest and flattest portion of the delta, until the onset of this millennium (when they were systematically drained), reed marshes, lakes, salt marshes, lagoons, tidal flats, and salt pannes dominated a transition zone where the waters of Mesopotamia pooled and then ultimately drained into the sea. The size and the geographical distribution of the patches in this watery quilt shifted over time, depending on rainfall at the rivers' headwaters, monsoonal cycles affecting winter and early summer rains at the head of the Gulf,

marine incursion and withdrawal, river sediment load and deposition, and upstream water impoundment for agriculture.

Three bodies of evidence inform our reading of this context: (1) excavations at sites in the southern reaches of the alluvium (for example, Uruk, ‘Oueili, Larsa); (2) geomorphologic investigations of ancient watercourses and of the extent of the mid-Holocene marine transgression of the Arabian-Persian Gulf into the area; and (3) assessments of the climatic conditions during the mid- to late Holocene. Taken in toto, such evidence suggests that by c. 6000 B.C.E., toward the close of what appears to have been the first substantial sedentary occupation of that region (that is, Tell’Oueili, Ubaid “o” levels), eustatic and local sea-level rise had extended the head of the Gulf as far inland as modern Basra (Huot 1989, 1991, 1996; Sanlaville 1989, 1996, 2003). The exact borders of the mid-Holocene shore(s) are ill defined, but it is clear that, over the course of the next two millennia, at its maximum level the sea submerged the lands encompassing much of the modern Iraqi administrative districts of Amara (Maysan), Muntafiq (Dhi Qar), and Basra (Figure 1).

Within the resulting inner delta, a dynasty referred to as “the Sealands” first appears in cuneiform records dating to the middle of the second millennium B.C.E., but similar conditions are likely to have existed from the onset of urban life in this region two millennia earlier. For example, what would become the great city of Uruk appears to have grown from separate, parallel settlements founded on the higher patches of marshy ground contained within the toes of an archaic bird’s-foot delta, where a main branch of the Tigris-Euphrates river system as it then existed debouched into vast marshes at the head of the Gulf (Pournelle 2003a-b; 2007: Figure 13; Brückner 2003: 243). Uruk cylinder seals and carved stone vessels portray newborn livestock emerging from large, arched-roof reed structures that are strikingly similar to reed sheep and cattle byres, commonly found in modern times at marsh edges (Amiet 1961: 77, plate 46, nos. 623, 629a, plate 47, no. 632; Kawami 2001: Figures 4e, 7a–b, 14a–c; Winter 2007: 121–122, Figures 29–30). Presumably, those fourth-millennium representations presage the “reed pastures” or “reed gardens” that figure prominently in later third-millennium texts from Umma, Drehem, and Girsu, as places where agricultural products were stored and distributed, domestic livestock were born and fattened, and “fields” were allocated for harvest of wood, reeds, and grasses (Steinkeller 1987; Waetzoldt 1992; Brunke 2008; Widell 2009; Heimpel 2010).

Both modern ethnographic observations (Table 1) and the ancient textual sources suggest that what would become known as “The Sealands” provided substantial and easily exploitable food, fodder, fuel, and raw materials (minimally including fish, reeds, dates, flax, salt, dyestuffs, and shell)—although, absent properly excavated samples, we cannot yet quantify their economic importance (Englund 1990, 1998). In this model, we would therefore expect (and

do see) urban growth near the heads of avulsive splays that feed large stands of marsh grasses and pasturage and provide the ground for date palm gardens and opportunistic barley cultivation (Figure 6) (Verhoeven 1998: Figure 2; Wilkinson 2003: 88, Figure 5.9; Wilkinson 2001: 255). Cities such as Umma would, in their time, have lain in a setting similar to that of modern Amara, albeit closer to the salt pastures of the lower estuaries. The modern transition zone from the southern Hammar belt to Fao on the Gulf coast may be compared to the ancient transition zone south and east of Warka, with Uruk in the position of Qurna (or, through time, Nasiriya) and Ur in the position of Fao (or, in time, Basra). Temporal and spatial patterning of smaller settlements presumably providing the wetland agronomic base for these urban centers supports this notion: from the early fourth millennium B.C.E., these move progressively east- and southward, until by the mid-third millennium they are no longer visible in Adams's zone of extensive survey (Pournelle 2003b: 204–212).

CONCLUSION

The potential for high crop yields from irrigation, supported by historical texts that record such high yields, have led scholars to link the success and failure of southern Mesopotamian urbanized communities to a subsistence base heavily dependent upon spatially and socially integrated agricultural systems extended by large-scale irrigation agriculture networks. For example, Gibson and Downing (1974), Gibson (1976), and Robert McC. Adams (1978) modeled the millennial flow of southern Mesopotamian history as an oscillation between periods of political stability, during which powerful territorial states attempted to maximize extraction of a narrow set of resources from ever larger domains, and periods of political disintegration, characterized by less efficient but more sustainable heterogeneous resource extraction strategies focused on risk avoidance and survival. They characterized these contrasting strategies of maximization and resiliency in the Mesopotamian alluvium as largely involving different intensities in the use of irrigation networks, different decisions about the types of land brought into cultivation at any one time, and different strategies in the implementation of fallowing intervals in that land.

While this approach is not incorrect, it is incomplete. An equally—if not more—salient reason for long-term urban success within the deltaic landscape of southern Mesopotamia was that the region lent itself particularly well to the adoption of resilient niche-construction strategies by the societies in its midst. History has shown that the large, alluvium-wide agricultural systems were in use only during relatively brief periods of strong centralization. However, during either political phase—centralized or decentralized—urban trade and distribution centers continued to grow at avulsive splay heads, where wetland harvests



FIGURE 6. *Abandoned, undated, mixed residential-agricultural zone (outlined) spanning 4,000 ha across three crevasse splays (dashed lines) debouching from an archaic Euphrates channel (black line), about 1 km east of Tell Abu Salabikh in the “Sealands” of the southern alluvium. The inset shows the detailed preservation of waterways, palm gardens, irrigated basins, house foundations, stock pens, and so on throughout this area.*

supported livestock production, construction, packaging, and fuel needs. Over time, as the delta prograded and their wetland base migrated away, upstream cities expended progressively more effort to maintain and manage those avulsions, eventually becoming ever more dependent on irrigated agriculture to bolster local food supplies and on concomitant political control over ever more distant supporting settlements. However, downstream, burgeoning population centers could then grow around new splays. Ideally situated to draw in resources from multiple distributaries, these new centers would be essentially unconstrained in size, and their initial form would intermix pasturage with settlement enclaves and urban gardens (Figure 6).

Thus, seemingly small but key differences in microtopography not only created but also continually re-created specialized niches within the landscape that allowed for the integration of a diversity of agricultural and subsistence practices. The variant field systems traced on the remote sensing and other spatial data sets and recorded from the historical texts record overt successes in creating sustainable, resilient, and replicable agricultural zones by (1) focusing plow agriculture on the long-lived levees systems, annually rejuvenated by inundation; (2) adjusting field size, irrigation gradients, and drainage offtakes to maximize

use of natural topography; and (3) colonizing new “sealands” created by downstream deposition of water and sediments, thus “recapturing” soil, water, and nutrients displaced by long-term interaction of “natural” and “anthropogenic” processes. While, in other contexts, the niche constructions that constitute agricultural landscapes can result (and have resulted) in irredeemable environmental degradation, ultimately requiring massive changes in agricultural practice to ensure human survival (Wilkinson 2003), within the deltaic context of southern Mesopotamia they have provided resilient and sustainable sustenance for the development and maintenance of social complexity and urban life over a span of some six millennia.

Notes

1. Adams 1965, 1972, 1981; Roux 1960; Jacobsen 1954, 1960, 1969; Adams and Nissen 1972; Directorate of Antiquities 1976; Wright 1981; Carter 1990; Wilkinson 2000.

2. Field 1936, 1949; Wirth 1955, 1962; Salim 1962; Westphal-Hellbusch and Westphal 1962; Thesiger 1964; Fernea 1970; Hassan and Criddle n.d.; Ochsenschlager 1993, 2004; Jawad 2006; Pournelle and Algaze 2010.

3. Al-Azzawi 1986; Al-Baidhany, Darmonoian, and Albadran 2002; Aqrabi and Evans 1994; Aqrabi, Domas, and Jassim 2006; Bernier, Dalongueville, Dupuis, and Medwecki 1995; Brückner 2003; Cotha Consulting Engineers 1959; Gasche and Tanret 1998; Geyer and Sanlaville 1996; Hall and Palmer 2000; Heyvaert and Baeteman 2008; Lambeck 1996; Larsen 1975; Lebeau 1989; Lees and Falcon 1952; Nützel 1978; Plaziat and Sanlaville 1991; Sanlaville 1989, 1996, 2003; Verhoeven 1998.

4. Al-Halilli, Warner, Asada, and Douabul 2009; Aqrabi 1997, 2001; Bar-Matthews, Ayalon, and Kaufman 1998; Cullen and Dermenoc 2000; Cullen, Kaplan, Arkin, and Dermenoc 2002; Dalongueville and Sanlaville 1987; Desse 1983; Doose-Rolinski, Rogalla, Scheeder, Lückge, and Von Rad 2001; El-Moslimany 1994; Frumkin, Carmi, Zak, and Magaritz 1994; Gillet 1981; Goodfriend 1990, 1991; Lemcke and Sturm 1997; Lézine, Saliège, Robert, Wertz, and Inizan 1998; Miller 1998; Moorey 1994; Moustafa, Pätzold, Loya, and Wefer 2000; Mudar 1982; Neef 1989; Potts 1997; Rosen and Weiner 1994; Rosen 1995; Safar 1950; Valladas, Evin, and Arnold 1996.

5. SRTM is an international project led by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). During an 11-day mission in February 2000, the Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale. See <http://www2.jpl.nasa.gov/srtm/>.

6. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument aboard Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System. See <http://asterweb.jpl.nasa.gov/>.

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Complexity, Rigidity, and Resilience in the Ancient Puebloan Southwest

Archaeology based on deductive rather than inferential logic has a long history in the U.S. Southwest (Martin 1971). Perhaps the abundance of data—stemming from pristine preservation, a thorough historic and contemporary ethnographic record, and the extensive coverage of archaeological survey in the region (Ortman et al. 2012)—has encouraged researchers in the Southwest to generate models with testable predictions and to bring the record to bear on these in a highly productive way. The development of computational models in particular has been accompanied by a call for a “model-based archaeology” oriented around the development and refinement of testable models for prehistoric behavior. Such an archaeology can also incorporate quantitative models similar to those used in human behavioral ecology. Phillips (2009), for instance, reviews recent efforts to model formally the spread of agriculture in the U.S. Southwest and presents a model that incorporates marginal costs of different subsistence strategies.

Until recently, however, archaeologists have shown restraint in—if not some resistance to—moving beyond linear relationships as models explaining the patterns they observe.¹ While these linear models have the benefit of being tractable and testable, some researchers—notably pioneers of historical ecology such as Crumley (1993)—have become dissatisfied with the simplicity of such models and have sought “complex-systems” approaches to organizing and analyzing archaeological data. Many of these approaches, including the agent-based computer simulations discussed here, evolved out of the ecological literature and the development of complexity theory at places like the Santa Fe Institute, the University of Michigan, and Arizona State University (Kohler and van der Leeuw 2007). After the ecologist C. S. Holling formalized the panarchy concept (1986), Folke (2006), Redman and Kinzig (2003), and others began developing the concept of resilience within socio-ecological systems, providing a framework—the notion of the “adaptive cycle”—for studying both the self-organization of such systems and their ability to withstand external perturbations. Although

resilience (and the closely coupled concept of sustainability) is becoming foundational for historical ecology, a slightly different body of theory on “robust systems” has been built up by researchers at the Santa Fe Institute and elsewhere (Jen 2005) and applied to Pueblo societies in the northern Southwest to help explain the area’s well-known thirteenth-century depopulation (Kohler 2010; Kohler et al. 2008). Elsewhere Kohler (2013) has suggested that analytically separating two aspects of sustainability—robustness and evolvability—may be more useful to archaeologists than is the concept of sustainability itself.

In this essay, though, we provisionally accept the bundle of concepts surrounding resilience, including the adaptive cycle, in order to analyze the possible applicability of one such concept—the “rigidity trap”—to the prehistory of Pueblo societies. Rigidity within a system refers to a winnowing of possible trajectories for that system. Put another way, rigidity is an attribute of a system that suppresses agency of actors within the system by limiting their possible behaviors. An example of this (explored later) is the depletion of a faunal resource such as deer on a landscape. If deer populations fall below a level where they may be reliably hunted, hunters must either hunt for animals that provide lower returns or find an alternative source of protein (domestic turkey, in our case). Thus, rigidity may be considered roughly the inverse of *diversity*—of available resources, of settings in which to live, or of possible alternative behaviors. Domains of rigidity can sometimes be static, such as the geographic space where people can choose to live, but they are more often dynamic, such as the faunal domain mentioned. A system becomes a “trap” (Holling 2001: 400) when its possible trajectories have been winnowed to one, a system where agency is effectively eradicated. We say “effectively,” because, although individuals might be able to make certain choices, those choices have little influence on the overall trajectory of the system. Holling distinguished between “rigidity” and “poverty” traps based on a notion of *connectedness* between agents in a system, a distinction beyond the scope here. In both traps, individuals lose meaningful agency, the system loses resilience (the ability to adapt to external perturbations), and eventually the system collapses.

Michelle Hegmon and colleagues sought to operationalize resilience theory—and specifically the rigidity trap concept—by focusing on episodes of systemic failure in the U.S. Southwest and by identifying domains of structural rigidity within those systems (Hegmon et al. 2008). Hegmon and colleagues focus on three iconic episodes of cultural collapse and reorganization in the region—the Hohokam in southern Arizona, the Mimbres in southwest New Mexico, and the Ancestral Pueblo people of the Central Mesa Verde region of Southwest Colorado, on which we focus. Each of these experienced dramatic and often violent social transformations in the final years of occupation. Hegmon and colleagues identify three ordinally measured domains of rigidity

accumulation in the study areas: degree of integration, degree of social power/stratification, and degree of technological conformity within each culture. They also use a relative ranking to quantify total degree of transformation, based on measures of the degree of change (from before to after the transformation) in different domains, including ceramic style, household organization, and architectural style. They also attempt to quantify human suffering from health problems and violence. They find a strong correlation between high rigidity in each of the three domains and the magnitude of transformation, and they suggest cultural attachment to traditions and technologies as a possible cause of the high rigidity. Cultural attachments and social stratification are the rigid structures that make up the trap, leading to transformations in each case (Hegmon et al. 2008: 321).

While Hegmon and colleagues offer a compelling application of resilience theory to portions of the prehistory of the Southwest, they stop short of fully explaining how rigidity may accumulate within the domains they identify. In fact, they don't document accumulation at all but instead focus on system rigidity just before the transformation of each culture. The concept of a trap, though, is necessarily historic; if we are to study rigidity traps, we must seek to understand how they are baited as well as how they are sprung. To this end, Hegmon and colleagues could calculate how rigidity changes in the decades and centuries leading up to system transformation. A different strategy—pursued here—would be to develop artificial systems that tend to evolve toward structural rigidity, identify archaeological correlates to aspects of those artificial systems, and focus our empirical efforts on testing whether archaeological data support those models.

Agent-based simulation (ABS) is one way to develop artificial socionatural systems; ABSs can generate high-level (system) patterns (such as rigidity accumulation) by specifying low-level (agent) behavior and observing the impact of bottom-up processes (Kohler 1999). In ABS, autonomous agents interact with one another in prescribed ways. By giving “agency” to many realms of a system—say, to humans as well as to their landscapes—we may create dynamic systems that more closely resemble systems in the past and that demonstrate cycles of resilience or rigidity over time. Through ABS, we may gain a greater understanding of how domains of rigidity, such as those identified by Hegmon and colleagues, interact with one another, often in complex ways. If we design such ABSs in the image of prehistoric societies, we may “fit” patterns in the record to those produced by ABS as a way of testing hypotheses derived from the resilience construct (Grimm et al. 2005; Kohler and van der Leeuw 2007).

In this essay we introduce one such ABS—that created by the Village Ecodynamics Project (VEP) for the Puebloan Southwest (Kohler, Bocinsky, Crabtree, et al. 2012; Kohler and Varien 2012; Varien et al. 2007)—and give examples of

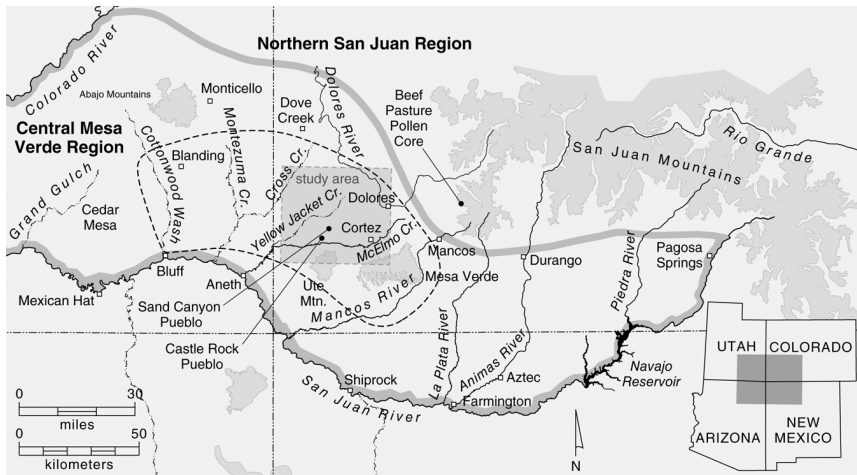


FIGURE 1. *The Northern U.S. Southwest, including the Northern San Juan basin (beige border), the Central Mesa Verde region (dashed border), and the Village Ecodynamics Project study area (in green). Adapted from Kohler and Varien 2012: Figure 1.1.*

how output from such an ABS might be useful in identifying coupled domains of rigidity buildup, as well as quantifying that buildup over time. We give special attention to the role of protein procurement and present a processual model outlining how the intensification of turkey (*Meleagris gallopavo*) use in the Puebloan Southwest might have initiated a multidomain feedback, increasing rigidity and contributing to the eventual collapse of Pueblo societies in Southwest Colorado.

PROTEIN SUBSISTENCE IN THE VILLAGE WORLD

One goal of the VEP is to generate an agent-based computer simulation of coupled human-ecosystem dynamics in a relatively large region of the northern American Southwest (Kohler and Varien 2012; Varien et al. 2007). In the model, an initial number of independent agents are loosed on a landscape resembling—with reasonable fidelity—the central Mesa Verde region in southwestern Colorado (Figure 1). The agents, representing households, are able to grow maize, hunt, and trade maize and protein. Individuals within households procreate, die, and marry to form new households. The region in which the model is set enjoys one of the most thoroughly analyzed archaeological records in the world. The simulation output can therefore be compared to the archaeological record, both spatially (in terms of distribution of sites on the landscape) and demographically (in terms of numbers of households), while varying a

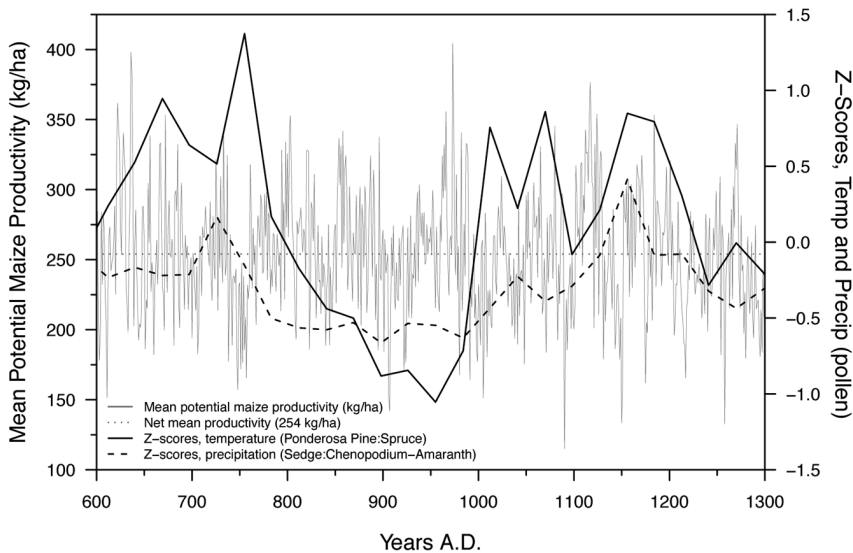


FIGURE 2. Maize paleoproductivity reconstruction for the Village Ecodynamics Project area. The solid gray line represents annual average potential maize yield in kilograms per hectare; the dotted gray line is the average of the series. Temperature and precipitation proxies from pollen cores are given in solid black and dashed black lines, respectively. Adapted from Varien et al. (2007).

number of model parameters. By doing this, VEP researchers identify causal processes—both social and natural—for changes in population size and distribution (Kohler et al. 2007), including the famous depopulation of the entire region in the late A.D. 1200s. Our results are fully reported in contributions to Kohler and Varien (2012).

The VEP studies a 1816 km² area of southwestern Colorado, modeled as 45,400 200 x 200 m cells. In the simulation floral and faunal resources are managed by each cell. Our model landscape provides sources of protein in the form of three nondomesticated herbivore populations—mule deer (*Odocoileus hemionus*), black-tailed jackrabbits (*Lepus californicus*), and desert cottontails (*Sylvilagus audubonii*)—that vary in size spatially and temporally (Cowan et al. 2012). They “grow” on a model landscape that contains 139 soil complexes, each of which supports some combination of 93 plant species. Animal population sizes depend in part on how much of their preferred browse is available within local plant communities. Browse production in turn is controlled by the action of a climatic signal derived from tree rings on a soil of a specific category, modulating its reconstructed stored moisture (Johnson and Kohler 2012; Kohler 2012a, 2012c).

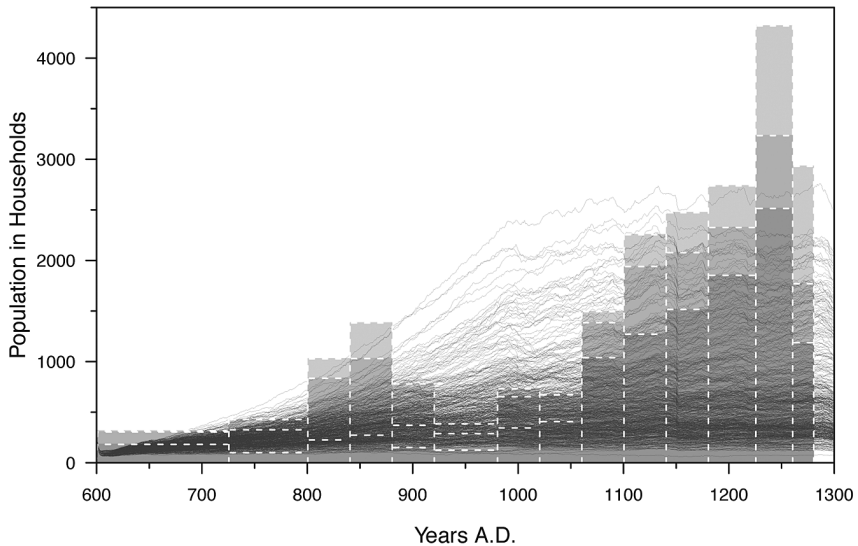


FIGURE 3. *Simulated populations from 512 runs of the Village Ecodynamics Project simulation, varying nine parameters in two states each (in dark gray), overlaid on three population estimates for the VEP study area (shaded histogram in background). In all but the highest-population runs, simulated populations quit growing by about 1100, while real population estimates continue on an upward trajectory. Adapted from Kohler and Varien (2012).*

Our climate signal and soil productivity estimates build on pioneering work by Carla Van West (1994). Like her, we apply instrumented weather data to data from soil surveys to reconstruct Palmer Drought Severity Indices (PDSI), a measure of soil moisture retention, for each soil, then retrodict these back to A.D. 600 using tree-ring data to proxy PDSIs, given a strong correlation between the two for the modern period. Maize reconstructions (Figure 2) also depend on proxy temperature data from high-elevation bristlecone pine series, with higher temperatures leading to increased maize yields. Another critical climate signal is provided by pollen analyses. Aaron Wright (2006, 2010) reconstructed low-frequency (>25 years) climate change and found evidence for significant cooling from roughly A.D. 850 to A.D. 950 and in the 1200s, in general agreement with earlier studies for this region (Petersen 1988). This low-frequency signal is *not* included in our maize paleoproductivity calculations, a likely cause for the departure of the simulated and real population trajectories in those periods (Figure 3).

Human hunting has a dramatic impact on faunal populations in the simulation. Perhaps the most striking pattern we see is how quickly agents significantly

deplete the simulated deer population, usually bringing deer density on the landscape down to about 0.9 deer per square kilometer (from a baseline of 7 deer/km² with no human or other predation; Johnson 2006: 190) by A.D. 1000, 400 years after the simulation begins (Bocinsky 2011; Bocinsky et al. 2012). At this stocking level deer hunting is difficult, as the low density of deer on the landscape entails high search costs. These in turn keep human populations relatively low; as we see in Figure 3, simulated human populations level off—and fall below levels estimated by the archaeological record—at about the same time that deer become depleted.² This is partially the product of not allowing for more nuanced protein procurement strategies in the simulation, such as the domestication of turkey. Turkey remains show up in the zooarchaeological record throughout the farming occupation of the northern Southwest and become dominant as a protein source in the mid-eleventh century A.D. (Badenhorst and Driver 2009). Elsewhere, Bocinsky (2011) demonstrates that turkey use and eventual domestication allow simulated human populations to continue their upward trajectory.

RESIDENTIAL RIGIDITY IN THE PUEBLOAN SYSTEM

We now focus on aspects of residential mobility and subsistence that, we argue, display evidence of buildup of rigidity within Pueblo society. We take the mean use-life of residential sites as a proxy for residential rigidity; this may be connected to “attachment to place,” which Hegmon and colleagues (2008) identify as a possible cause for societies to fall into a rigidity trap. Such attachment might be motivated, in part, by sunk costs (Janssen et al. 2003) in the societies referenced by the simulation. In 2007 Varien and colleagues (2007: note 27, Table 3) tabulated empirical Puebloan site use-lives in the VEP study area, reconstructed from artifact accumulation data. They identified two primary relationships: first, use-life generally rose throughout the study period (A.D. 600–1300), both for small sites and for community centers, which they define as sites having communal architecture or nine or more pit-structures. They also found that use-life did not covary in a simple way with regional population size, as might be expected. While use-life did increase with initial population growth, it does not appear to have decreased when population decreased in the late first millennium A.D. This is slightly counterintuitive, since we might expect that lower populations would allow residents more flexibility to move should another area become more productive.

Data from the VEP simulation may be used to clarify why population size seems to have only an upward effect on site use-life and why it seems to increase throughout the study period. Figure 4 is a kernel density smooth³ of site use-life in 512 runs of the VEP simulation under varying parameter settings, displaying

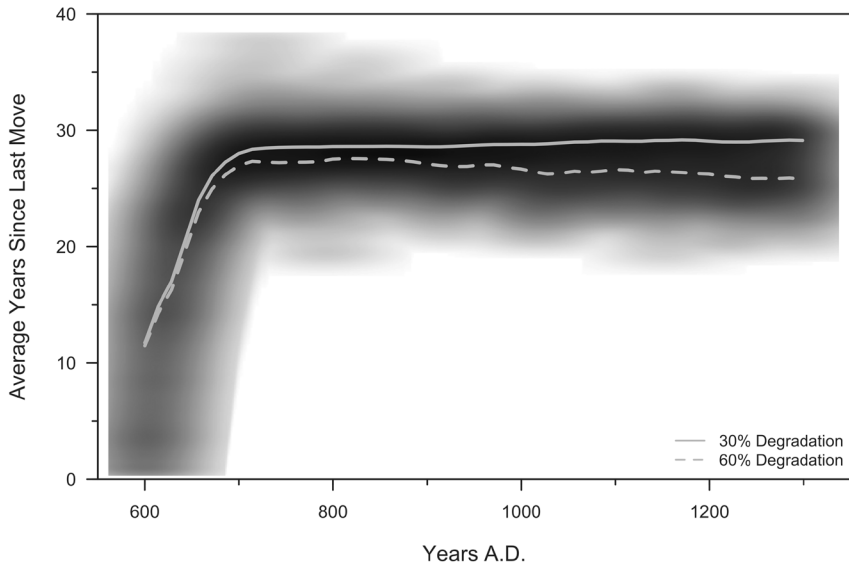


FIGURE 4. A kernel density smooth of site use-life in 512 runs of the VEP simulation under varying parameter settings; average time since last move (vertical axis) and year (horizontal axis). Mean values for the rate of soil degradation agents experience when farming are given in solid (30% degradation) and dashed (60% degradation) gray lines.

average time since last move on the vertical axis against calendar years on the horizontal axis. The kernel density smooth allows us to remove much of the stochastic annual variation in average site use-life and to extract general trends. This graph shows that the simulations exhibit two primary trajectories, corresponding to heavy (dashed gray) and light (solid gray) parameter settings for the rate of soil degradation agents experience when farming repeatedly in a single location.⁴ Real site use-lives track those produced by the “light degradation” setting for soil degradation after A.D. 1060, better than they do the use-lives produced by the heavy-degradation parameter setting. (An analysis by Kohler, Bocinsky, Crabtree, et al. 2012, using a different logic, comes to the same conclusion.) Possibly farmers in these societies were actively managing their soils to allow them to remain at sites for longer periods.

It is important to understand that site use-life is not a parameter that we set in the simulation; use-lives emerge in the simulations from a relatively complex interaction between the condition (productivity) of the landscape and the numbers and locations of households on that landscape in each year. There are many possibilities why use-life might continue on its (slight) upward trend

in simulations employing the light soil-degrade parameter. Nonstationary resources such as deer generally are depleted readily on the simulated landscape, and their populations continue to be suppressed throughout the simulation. This has the effect of raising the relative importance of more static resources—agricultural potential productivity, water, and highly local protein like rabbits and hares—in household relocation decisions. If agents are unable to locate deer within their search radii, deer location has no impact on locational strategy (Cowan et al. 2012; Kohler, Bocinsky, Crabtree, et al. 2012).⁵ In the real world, other agent behaviors, such as entering into trading relationships, also could increase the importance of these more stable resources if agents were able to specialize in their production and then barter with other households for other products. We explore this elsewhere (Cockburn et al. 2013); in the simulations reported here no specialization is allowed.

So far we have identified an archaeological rigidity buildup (residential rigidity, as proxied by site use-life), connected it to a simulated, archaeologically invisible socionatural attribute (persistence of agricultural productivity, as proxied by the rate of soil degradation), and suggested several other behavioral domains in which rigidity buildup might reinforce residential rigidity (protein and water availability, trade networks, and specialization). Other domains in the past may well have been as important as or even more important than the ones we suggest here. However we would like to spend the rest of this essay suggesting how one domain, subsistence, likely became tightly coupled with residential mobility via turkey domestication. Furthermore, we propose that agent-level behavior in both subsistence and residential domains had positive-feedback effects on each other, such that success in one domain reinforced rigidity in the other and vice versa. We call this process the Avicultural Trap.

SUBSISTENCE RIGIDITY AND THE AVICULTURAL TRAP

The VEP study area (Figure 1) saw substantial demographic change during the thirteenth century A.D., including dramatic aggregation around canyon heads followed by complete depopulation by around A.D. 1280 (Duff and Wilshusen 2000; Lipe and Ortman 2000; Varien et al. 2007). Several models employing both ecologically and culturally based accounts have been created in an attempt to explain this massive depopulation. Researchers have long agreed that while regional drought was a principal cause of emigration, sociocultural influences likely directed the trajectory (literally and figuratively) of the migrations (Lipe 1995). Recent research—including that of the VEP—is beginning to clarify the roles of low-frequency temperature and precipitation signals proxied by pollen data and their interaction with high-frequency variability proxied by tree-rings

(Wright 2006, 2010; Kohler 2010). It now appears that satisfactory models for the initiation and the direction of the regional emigration must include demographic, social, climatic, and environmental factors.

One such factor, noted earlier, was the tendency (both in the model and in the record) of expanding local populations to deplete wild protein resources, leading (in the record) to reliance on an avicultural strategy. This strategy, in turn, may have encouraged population aggregation and certainly favored agricultural (maize) intensification. The eventual importance of maize for both calories and protein not only decreased the latitude (as this term is used by Walker et al. 2004) of the subsistence and settlement systems but may have indirectly driven increasing rigidity in other domains of Pueblo society, given the centrality of maize to Puebloan ritual. In the rest of this essay we present a somewhat idealized version of historical events, aimed at articulating one way in which turkey use might be implicated in the buildup of structural rigidity in the NSJ and in its eventual abandonment.

A.D. 600–900: INITIAL IMMIGRATION AND GROWTH

Small communities of maize agriculturalists moved into the region around A.D. 600 (Varien et al. 2007: 275–276, 283). Populations were initially distributed as small hamlets (typically of one or two households each) across the landscape (Varien et al. 2007: 284). Their tendency to be more dispersed than the agents in our model suggests that in some sense households interfered with each other (Kohler 2012b: Plate 15.1). The most likely explanation for this, in turn, is that their subsistence activities were heavily focused on the areas around each hamlet. Deer were an important meat source during this time relative to leporids (Badenhorst 2008; Badenhorst and Driver 2009). Population grew until the late 800s (Varien et al. 2007: 285). The villages that formed beginning in the mid- to late 700s began to impact deer availability (Duff et al. 2010: 173; Kohler and Reed 2011), though not so much as would later populations in this area. Turkey were kept at sites in small numbers and were used primarily for feathers and as a ritual resource (Muir and Driver 2002:174; Munro 1994:149).

A.D. 900–1060: COUNTEREXAMPLE ~ RESILIENT POPULATION DECLINE

A period of dry and cold years from the late 800s through at least the mid-900s reduced agricultural productivity across the landscape (Varien et al. 2007: 279; Wright 2006). Populations declined regionally, and large villages disappeared from the VEP area (Varien et al. 2007: 290). Maize agriculture and deer, rabbit, and hare hunting of course continued, though there was a shift away from deer

toward leporids in some areas (Duff et al. 2010:173). Turkey continued to be used only or primarily as a ritual resource (Munro 1994: 149). Lower agricultural yields possibly discouraged turkey raising.

A.D. 1060–1250: DEPLETION OF DEER AND THE
BAITING OF THE AVICULTURAL TRAP

Human populations grew rapidly in the last half of the A.D. 1000s (Varien et al. 2007: 285), probably aided by immigration to the NSJ of peoples with Chacoan affiliations from the south (Lipe 2006; Varien et al. 2007:289). Deer populations declined and remained depressed after this point (Bocinsky et al. 2012; Duff et al. 2010:173; Johnson 2006). Households may have “chased” deer across the landscape as deer populations in areas of high maize production became severely depressed (Bocinsky 2011; Bocinsky et al. 2012). With continued population growth human populations continued to aggregate into communities (Varien et al. 2007); households became more clustered in areas on the periphery of the remaining areas of relatively high deer productivity (Bocinsky 2011). People in areas of high maize productivity (which also supported the densest populations) raised turkey (fed in part from maize) as it became less calorically expensive to feed and raise turkey than to hunt for other protein. This “avicultural strategy” stimulated a greater dependence on maintaining surpluses of maize, as turkey feed on corn (almost exclusively in some places; Rawlings 2006: 166; Rawlings and Driver 2010). Wild turkeys (if available) may have initially been hunted for protein, but their populations, like deer, were likely rapidly depressed.⁶ There could have been a shift toward larger turkey phenotypes at this time (McKusick 1986). Human populations continued to increase even as they contracted spatially (Varien et al. 2007: 290), requiring further agricultural intensification. Hierarchical social structures emerged (Lipe 2002), as reflected by public and private architecture (Glowacki 2006). Intensification of maize production may have precluded spending more time on deer hunting, if these repopulated peripheral areas during this time, and might have encouraged specialization in other domains (Fargher 2009: 356). Population peaked at around 30,000 in the VEP area, driven in part by emigration from less favorable areas to the west and northwest (Glowacki 2006).

A.D. 1250–1280: TRANSFORMATION AND ABANDONMENT

Unfavorable agricultural conditions dominated the first half of the 1200s (Wright 2006: 122) and persisted into the late 1250s. These conditions improved in the late 1260s, but for only a few years (Varien et al. 2007: Figure 3). By A.D. 1270, a combination of emigration from the NSJ (Duff and Wilshusen 2000;

Wilshusen 2002:118–119), violence (Kuckelman et al. 2000), and the possible combination of high mortality rate and low fertility rate suggested by Varien (2010) but not yet systematically evaluated, reduced population size in the VEP area to approximately 10,000 people (Varien et al. 2007). Aggregation around fortified critical water sources, which began in the mid-1100s (Glowacki and Ortman 2012: Table 14.1), intensified; these may have been restricting resources on the landscape, potentially leading to competition over their control (Kolm and Smith 2012). By this period's end, communities abandoned turkey husbandry, possibly due to lack of maize surpluses (Beacham 2006; Kuckelman 2010a, 2010b). Populations reverted to hunting deer (Duff et al. 2010: 174) and perhaps wild turkey, as well as harvesting wild turkey eggs (Beacham and Durand 2007). Depopulation of the western portions of the NSJ likely began by A.D. 1240 and from the eastern portions by A.D. 1260 (Glowacki 2010). Most of the emigrants went to the northern Rio Grande (Ortman 2010; but see also Lekson et al. 2002).

OPEN QUESTIONS AND DISCUSSION

This narrative builds on many aspects of the archaeological record (transition toward turkey as protein circa A.D. 1050; aggregation in the most agriculturally productive areas in the twelfth and thirteenth centuries A.D., usually far from protein resources; final fortification in cliff-dwellings or canyon-head settlements, situated around critical water sources; and dramatic regional abandonment completed by ca. A.D. 1280), but questions remain. Paleoproductivity reconstructions—with associated estimates of human and domestic turkey-carrying capacity—will continue to enable us to quantify the degree to which people decided to shift their subsistence costs in favor of higher-quality local agricultural areas over nearby productive hunting grounds. Eggshell analysis (Beacham and Durand 2007), in conjunction with zooarchaeological evidence already collected, will indicate how people across the landscape differed in their degree of commitment to aviculture over time. Ancient and modern DNA studies (Mock et al. 2002; Speller et al. 2010) will contribute to our understanding about how turkey use varied across the landscape before and after aviculture was adopted, as well as while it was being intensified (Zeder et al. 2006).

Throughout this narrative we have used a broad definition of turkey use that includes controlled feeding and to some extent controlled breeding. This definition does not, however, capture the complexity of the turkey/human relationship (Bocinsky 2011: Chapter 1). Domestication is an especially intensive stage of an evolving mutualism between humans and an animal species. The intensity of a mutualism may be measured by the degree of codependence two species have on each other (Zeder et al. 2006). It may be the case that humans developed

a closely linked (and thus highly rigid) mutualism with a specific subspecies of turkey, *M. g. intermedia*, during the millennia of turkey use in the region (Speller et al. 2010). Such a codependence with a single subspecies might explain the demonstrated dominance of a probable *M. g. intermedia*-derived matriline of *M. g. merriami* in the archaeological record (Speller et al. 2010) and the perplexing dearth of the domestic matriline in modern wild populations regionally (Mock et al. 2002). We can therefore postulate that people either transported their turkey with them when departing the northern Southwest, butchered all of their turkey before leaving, or left domestic turkey behind—possible in a poor turkey habitat—that were ill adapted to feral living. Rigidity impacts all parts of a system, and it may be the case that domestic mutualisms are by definition particularly rigid systems, especially when unified by a common diet provided by maize agriculture and sparse water sources.

CONCLUSION: COUPLED DOMAINS OF RIGIDITY

The two domains of rigidity described here—residential and subsistence—are of course intimately linked. Intensifying turkey domestication generates a need for more substantial and stable agricultural yields and will drive movement to the most productive lands and increased devotion to maximizing agricultural productivity (perhaps through soil modification and definitely through construction of soil- and water-retention features; Benson 2011a, 2011b; Schlanger 1988; Wilshusen et al. 1997). This agricultural intensification and the population aggregation that occurs as people move to the best land in turn hasten the depletion of local wild protein resources and increase dependence on domestic meat; this feeds back into increasing agricultural demands. The entire cycle between residency and subsistence allows for continuing population growth, up to a theoretical limit supported by potential maize productivity. Figure 5 illustrates this process as a corkscrew. The system cycles through intensification of maize and turkey production, building rigidity within the system with each “rotation”; population is able to increase throughout this process, as people can transition from wild protein in favor of turkey; and the radius of the spiral symbolizes the amount of rigidity (and lack of agency) in the system. As the population grows, the trap is set, and meaningful agency is squeezed out of the system. As the population nears the theoretical carrying capacity of the landscape, it becomes more sensitive to years with extremely low maize yields, such as occurred in the mid-1100s and early and mid-1200s (Figure 2) and constricts agency further. The potential for large-scale starvation events increases during these periods, and the threat of these or of resulting warfare provokes the eventual exodus.

An agent-based framework allows for the reintegration of multiple fields of ecology, repeatedly presented as divergent by Balée (1988, 2006). At the most

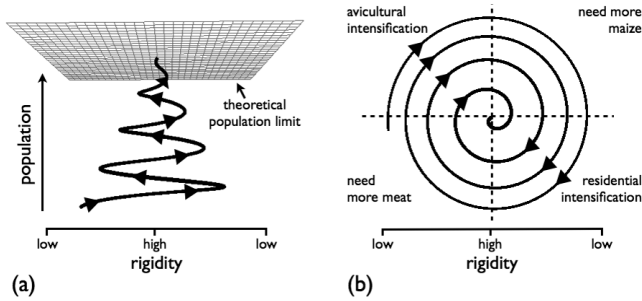


FIGURE 5. *Schematic of rigidity feedback between the residential and subsistence domains of rigidity, and their relationship to population and system rigidity. (a) Intensification in each domain allows for population increase (vertical axis) toward a theoretical population maximum, during which the system becomes more rigid (horizontal axis). (b) Two-dimensional representation of the same system. The radius of the spiral represents system rigidity. Agents go through periods of avicultural (top-left quadrant) and residential (bottom-right quadrant) intensification, spurred on by needs for more meat (bottom-left quadrant) and maize (top-right quadrant), respectively.*

immediate and local scale, human behavioral ecology (Winterhalder and Smith 2000) and event ecology (Walters and Vayda 2009) offer essential insight into agents' interactions with their local, momentized environments. Anthropological systems ecology and landscape ecology (Gillson 2009) are useful in describing how culture adapts to ecological systems, even constantly changing ones. Historical ecology, armed with the resilience concept and rendered useful by quantification, describes the stability of the entire system, at all its levels, and presents data at a scale that may be operationalized archaeologically.

Other essays in this volume present models that would benefit from specification in an agent-based framework. For instance Whitley's least-cost-path foraging model could be implemented on a per-agent basis to explore how resource depletion occurs on a landscape of interacting least-cost-paths. More work needs to be done though, especially in generating the tools necessary to quantitatively describe complex socionatural systems. While it soon may be possible to identify rigidity accumulation in various domains of a system (or proxies of such at various scales), the statistical tools are still being developed that will allow us to ascribe causation to that rigidity in episodes of a systemic collapse and reorganization. Identifying correlation between discontinuous decreases in rigidity and systemic reorganization—as Hegmon and colleagues do—is a start, but this approach is hindered by the classic lack of counterfactual data. For example, we cannot know archaeologically whether any of the

transformations they identify would have differed in intensity or even whether they would have occurred at all if one or more of the domains they studied had been less or more rigid. Simulation, alternatively, allows us to glimpse the possibility of exploring the complete distribution of counterfactual situations, generate data sets for those counterfactual virtual realities, and develop appropriate models for causal inference within such complex systems.

Notes

1. This statement is perhaps unfair; it is not to say that archaeologists have not recognized the complexity of human-environment interactions in the past. Rather, it might be that we have lacked the tools necessary to build models that can cope with such complexity. This barrier is being rapidly overcome, and thus our models are evolving.

2. This account is somewhat simplified; in fact we can vary the extent of the effect that protein depletion has on human population size via a parameter called “protein_penalty,” as explained in Bocinsky et al. (2012). Also there is some switching from hunting deer to hunting leporids, since our hunting algorithm is modeled on optimal foraging theory principles. Return rates for leporids are, however, relatively low, compared to those from deer when it is abundant.

3. This was performed using the function “smoothScatter” in the R statistical environment (R Core Team 2012). Multivariate kernel smoothing is described by Wand (1994).

4. The soil degradation rate is set to either 30 percent (light degradation) or 60 percent (heavy degradation); a fully farmed cell will lose this percentage of productivity over six years but never more than that.

5. This is the case even when our agents are highly protein deficient, though in some runs these agents perish because of this deficiency, and in all runs they suffer reproductively because of it.

6. The evidence supporting wild turkey hunting—and especially the eradication of wild populations—is sparse. Local (Duff et al. 2010; Munro 1994) and regional (Badenhorst 2008; Badenhorst and Driver 2009; Muir and Driver 2002) archaeological faunal analyses indicate a trend in which deer became less abundant as turkey became more so. However, lagomorph abundances also increased, as do lagomorph indices (Badenhorst and Driver 2009: 1838). This suggests enhanced focus on prey that were likely lower-ranked than turkey, indicating either that turkey were not abundant on the landscape to begin with or that their populations were swiftly depressed.

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Soil Texture and Agricultural Resilience in the Prehistoric Southwest

Farming on Perry Mesa, Arizona

In semiarid environments like the U.S. Southwest, water is the key limiting factor in the sustainability of crop production (for example, Muenchrath and Salvador 1995). Southwestern archaeological research on farming has thus focused in particular on how prehistoric farmers managed access to water so that their yields would be resilient to intra- and interannual variation in precipitation. These studies have been concerned with technology (for example, irrigation canals, check dams, terraces, and rock piles) and catchment—the nature and scale of the drainage area feeding into fields (Doolittle 2000; Kruse 2007; Sandor 1995).

More recently, however, research on dry farming has highlighted soil texture as a key factor affecting the degree to which the surface water that runs onto fields infiltrates and is retained within the soil profile and thus is available to agricultural crops. Soil texture affects water retention and availability to crop plants and also influences soil structure, bulk density, erodability, oxygen availability, and nutrient availability (Sala et al. 1988). Managing soil texture for optimal plant water availability may thus be one way to enhance resilience in agricultural systems in arid and semiarid environments.

Researchers working with contemporary corn farmers in semiarid landscapes in the Southwest and Peru, and with an archaeological perspective in mind, have in fact documented soil texture as a factor affecting the choice of field locations (Dominguez and Kolm 2005; Norton et al. 1998; Sandor and Furbee 1996; Muenchrath et al. 2002; Sandor et al. 2002). These projects have all involved contexts in which farmers have access to soils with textures appropriate for agricultural production (for example, silt and sandy loam). Not all farmers are in this position, however, and in the Southwestern archaeological case that we are currently researching farmers had access only to very clayey soils. Our

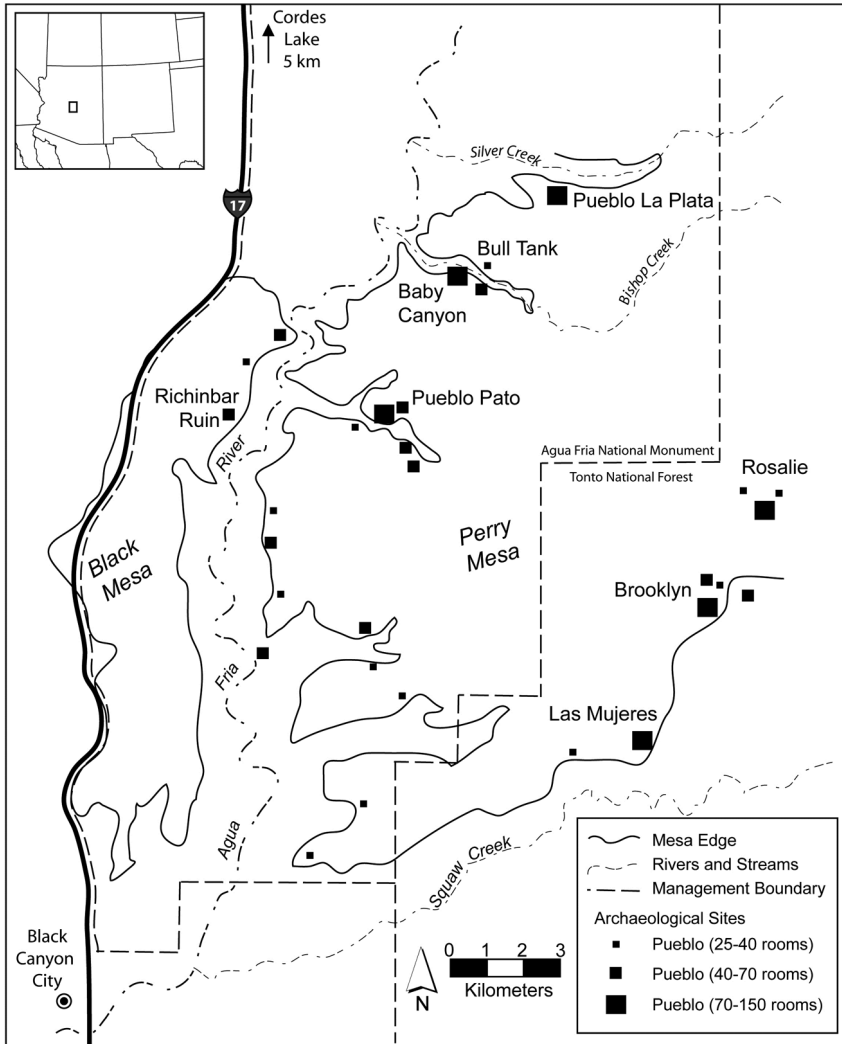


FIGURE 1. Map of Perry and Black Mesas, Arizona, showing locations of the larger archaeological sites.

research has thus focused on the actions prehistoric farmers may have taken to improve soil texture.

For more than a decade the Legacies on the Landscape project, an interdisciplinary collaboration between archaeologists and ecologists at Arizona State University, has been addressing soil manipulation on Perry Mesa in central Arizona (Figure 1). Mesa-top soils on Perry Mesa are classified as Vertisols, which exhibit poor infiltration because of a high surface fraction of shrink-swell

clays. Here, access to the kinds of loamy soils that are preferred for corn farming by traditional farming communities was limited. Possibly in response to the paucity of high-quality arable land, prehistoric farmers on Perry Mesa constructed large expanses of low terraces on their agricultural fields that affected sediment deposition in ways that appear to have improved the soil texture for farming.

In this essay, we introduce the Legacies on the Landscape project and discuss the relationship between ideal soil texture characteristics for corn farming from an ethnotaxonomic point of view and the degree to which Perry Mesa farmers may have manipulated the local soils toward those ideal characteristics.

LEGACIES ON THE LANDSCAPE

The Legacies on the Landscape project began in 2003 and was incubated in ASU's Center for Environmental Studies, which was established to encourage collaborative research between social and environmental scientists. The Legacies project is focused upon understanding the long-term legacy of prehistoric human land use on the ecology of semidesert grasslands in the southwestern United States.

Our case study is situated on Perry Mesa, primarily within Agua Fria National Monument (AFNM), 50 miles north of the Phoenix Basin in central Arizona. Perry Mesa is an ideal location for studying the ecological consequences of specific human actions because the landscape is characterized by a single, roughly 200-year occupation of farmers from approximately A.D. 1275 into the early 1400s. Intense human occupation did not recur on Perry Mesa until Anglo ranchers arrived in the mid-1870s, and cattle have grazed the area since that time. The Bureau of Land Management and the U.S. Forest Service administer the Perry Mesa landscape and regulate cattle grazing there.

The Legacies project has focused on the Perry Mesa Archaeological District and the fourteenth-century Perry Mesa Tradition occupation (Stone 2000), for which approximately 500 archaeological sites have been recorded. The settlement pattern consists of a series of larger masonry pueblos of close to 100 rooms distributed around the edge of the mesa and surrounded by a large number of dispersed one-to-ten-room habitation sites (Figure 1). Agricultural features are extensive and include linear soil and water control features (field borders and terraces), rock piles for agave production, and field areas conspicuously cleared of rocks (Fish et al. 1975; Gumerman et al. 1975; Kruse-Peebles et al. 2009; North 2002; Spielmann et al. 2011). As we have learned through extensive surveys on the mesa (Kruse-Peebles et al. 2009), Perry Mesa farmers subtly modified much of the landscape by creating modest one-to-two-course-high "terraces" of unmodified cobbles. Fortunately, when these farmers abandoned

Perry Mesa, these rock alignments remained, allowing us to identify prehistoric farming locations.

As our archaeology-ecology collaboration developed, we identified an overarching research question to guide our project: What are the ecological and social conditions under which human land use results in long-lasting transformations of ecosystem structure and function? Anthropogenic legacies that have been documented around the globe have shown that even relatively small changes to the environment can persist through centuries and even millennia in soils and plant communities (Bahre 1991; Caneva et al. 2003; Dambrine et al. 2007; Delcourt and Delcourt 2004; Dupouey et al. 2002; Foster et al. 2003; Gomez-Pompa et al. 1990; Heckenberger et al. 2003; Myster and Pickett 1992, 1994; Sandor et al. 1990; Schaafsma and Briggs 2007; Willis et al. 2004). Deciphering the relationship between human land use and ecosystem structure and function thus requires the time depth accessible through the archaeological record.

In the initial years of the Legacies project we focused on the ecological legacies of architectural construction and agave planting (Briggs et al. 2006; Kruse-Peoples et al. 2010; see also Parker et al. 2007). As the project developed, however, we realized that to address human actions that affect ecosystem structure and function we would have to investigate actions that had landscape-scale impacts. On Perry Mesa, the most land-extensive human action was corn farming. Our research is thus exploring whether these extensive activities have influenced physical and chemical properties of soil across the landscape.

SOIL ETHNOTAXONOMIES

It is common for small-scale farmers to use soil texture as the fundamental property on which they base their soil classifications, which convey information on the suitability of a soil for agricultural production. Research on ethnotaxonomies among traditional farmers in semiarid lands has established the richness of local soils knowledge, and in particular soil texture information (Dominguez and Kolm 2005; Ford 1999; Homburg et al. 2005; Muenchrath et al. 2002; Norton et al. 1998, 2001; Sandor and Furbee 1996; Sandor et al. 2002, 2006, 2007). These farmers tend to prefer loamy-to-sandy soil textures. A sandy stratum at the top of the soil profile promotes water infiltration, while a loamier soil beneath promotes water retention and more absorption of this water by plant roots (Dominguez and Kolm 2005; Muenchrath et al. 2002). A recent paper on soil hydrology by Dominguez and Kolm (2005) documents that on the Hopi Mesas particular kinds of plant cover signal the presence of these preferred soils.

While they provide a rich source of information, this published research on soil ethnotaxonomies, has generally focused on very long-lived (1,000 years or more) agricultural systems. Clearly, farming practices that promote or retain

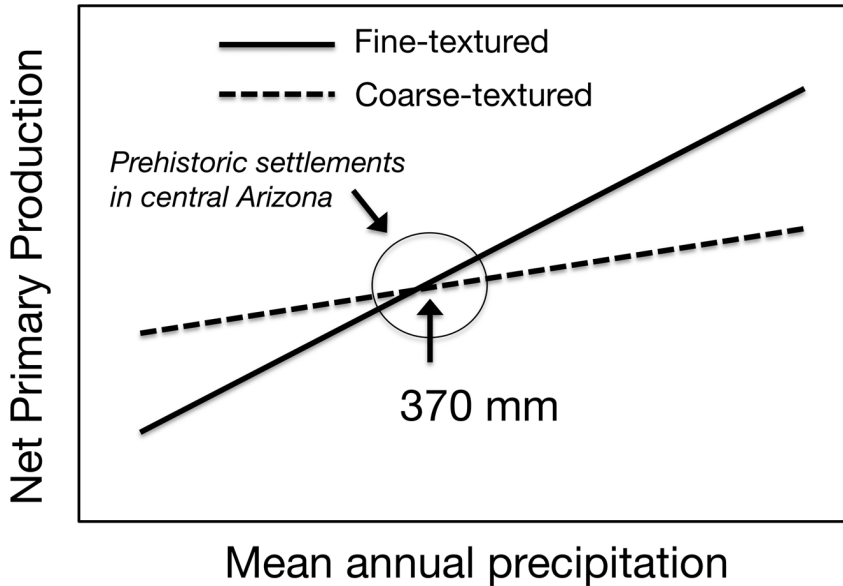
loamy-textured soils are sustainable. The Perry Mesa landscape, however, presented a situation that was likely common for prehistoric people, one in which soil textures for maize production were far from ideal (for example, Goodman-Elgar 2008). Our data suggest that measures may have been taken to ameliorate this situation.

PERRY MESA AGRICULTURAL SOILS

Soils on Perry Mesa are classified as Vertisols with a high surface fraction of shrink-swell montmorillonitic clays (Soil Survey Staff 2010). In regions that receive high rainfall or runoff, greater investments in labor and soil amendments, as well as technologies to manage soil moisture deficits and excess, are necessary for Vertisols to be successfully cultivated (Ahmad 1996). Without intensive management, however, Vertisols are generally problematic for crop production because of their tendency to hold water at potentials too low to be accessible by plants. At low water potentials, as when water is held to clay particle surfaces by adhesion, water is not free to move to plant roots. In addition, Vertisols are characterized by low water infiltration, high erodability, and deep cracks that form upon soil drying that may expose plant roots. Thus, in Cameroon, for example, Vertisols are generally considered to be marginal for crop production unless they are irrigated with river water or water reservoirs (Coulombe et al. 1996).

Managing vertic soils for agricultural productivity without modern technologies would have been difficult for farmers on Perry Mesa, in contrast to areas such as the Hopi fields that contain soils with coarser textures and nonshrink-swell clays (Dominquez and Kolm 2005). Ensuring water availability for crops during the summer growing season would have been particularly challenging on Perry Mesa because of the spatially and temporally patchy nature of monsoon precipitation, which occurs in intense pulses punctuated by long warm and dry periods. The Legacies project is investigating how it was possible for farmers to cultivate corn successfully on Perry Mesa for several generations given these environmental challenges.

Current ecological research by Sharon Hall, Dana Nakase, and Jolene Trujillo on Perry Mesa is investigating whether human-created rock terraces affect soil properties differently from natural rock alignments or outcroppings (Hall et al. 2013 and Nakase et al. 2014. And Trujillo 2011). Perry Mesa is characteristically a “rocky” landscape, and natural rock terraces that exhibit no human manipulation occur along the margins of the mesa. In these locations, we are measuring a suite of ecosystem properties and processes, including plant community composition, production of annual plants, and soil properties that contribute to productivity such as texture, water-holding capacity, and nutrient availability. According to the “inverse texture hypothesis” (Noy-Meir 1973), plant growth is higher on fine soils than on coarse-textured soils in ecosystems



Sala et al. 1988; Noy-Meir 1973

FIGURE 2. Relationship between soil texture, aboveground net primary production (ANPP), and mean annual precipitation. Above 370 mm of precipitation ANPP is higher in fine-textured soils, while below 370 mm of precipitation ANPP is higher in coarse-textured soils.

that receive ample amounts of rainfall because these soils exhibit greater water-holding capacity in the upper part of the soil profile, in plant-rooting zones. In warm arid and semiarid ecosystems, however, water tends to evaporate quickly from fine-textured soils, leading to less plant-accessible water in upper soil horizons. Thus, production of grasses is higher in coarse-textured soils in warm arid and semiarid ecosystems that receive less than 370 mm or so of annual rainfall, as these soils allow water to infiltrate deep enough to prevent rapid evapotranspiration to the atmosphere (Sala et al. 1988). Perry Mesa rainfall averages around 380 mm, putting it right at the transitional point between the optimal soil textures for net primary productivity (Figure 2).

Our data collection has focused on two agricultural complexes, one near Pueblo la Plata (NA 11648) and another near Bull Tank (Figure 1). The la Plata complex is approximately 7 ha (17.5 acres) in size and contains more than 100 linear alignments, several check dams, and a rock-pile area with a remnant agave colony. The Bull Tank Area (Figure 3) contains an extensive agricultural complex 10 ha (24.6 acres) in size, with more than 300 linear alignments and an adjacent remnant agave colony. We have also done a small amount of work on a small terrace system by Richinbar Ruin, and our surveys have documented a

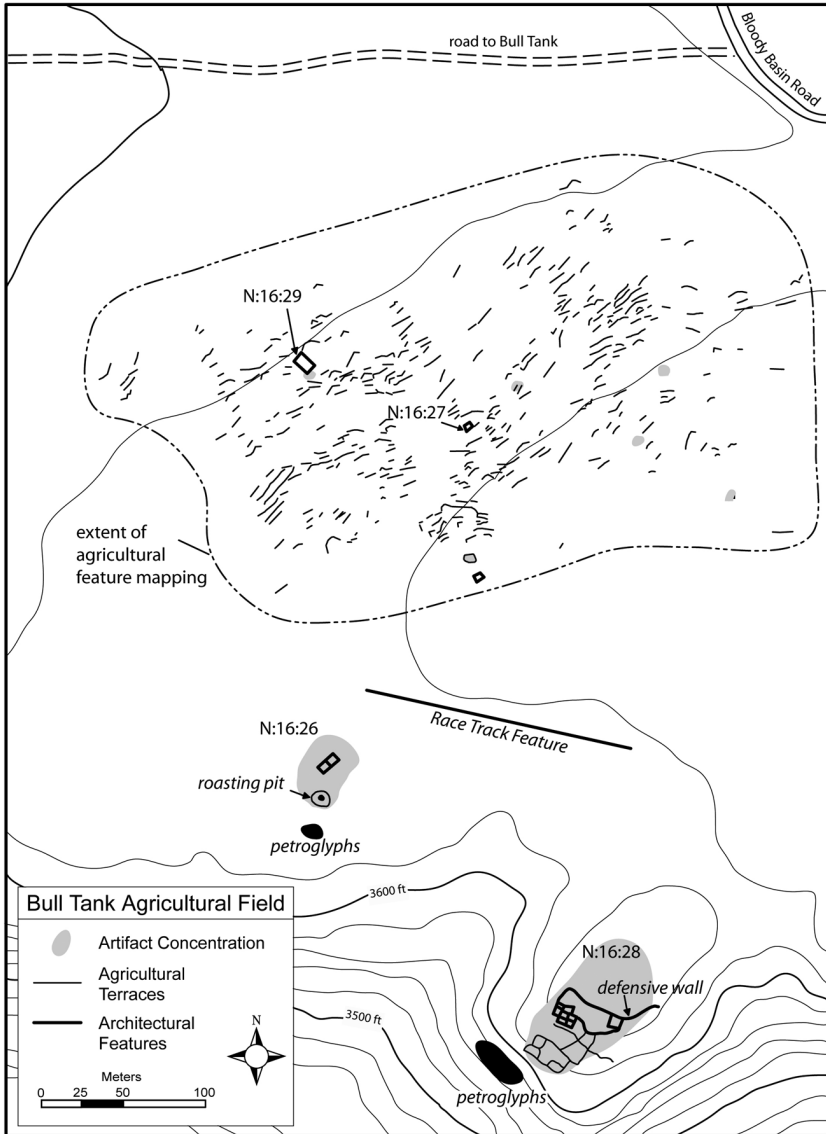


FIGURE 3. Map of the Bull Tank Agricultural Field, Perry Mesa, Arizona.

nearly continuous distribution of agricultural features including terraces, check dams, and rock-pile clusters near Pueblo Pato (Figure 1). This essay discusses some of the results from the Bull Tank analyses.

Our preliminary research suggests that, through their efforts to control the flow of water, prehistoric Perry Mesa farmers may have modified soil texture. This work on the subtle slopes and rock alignments present at the Bull Tank fields

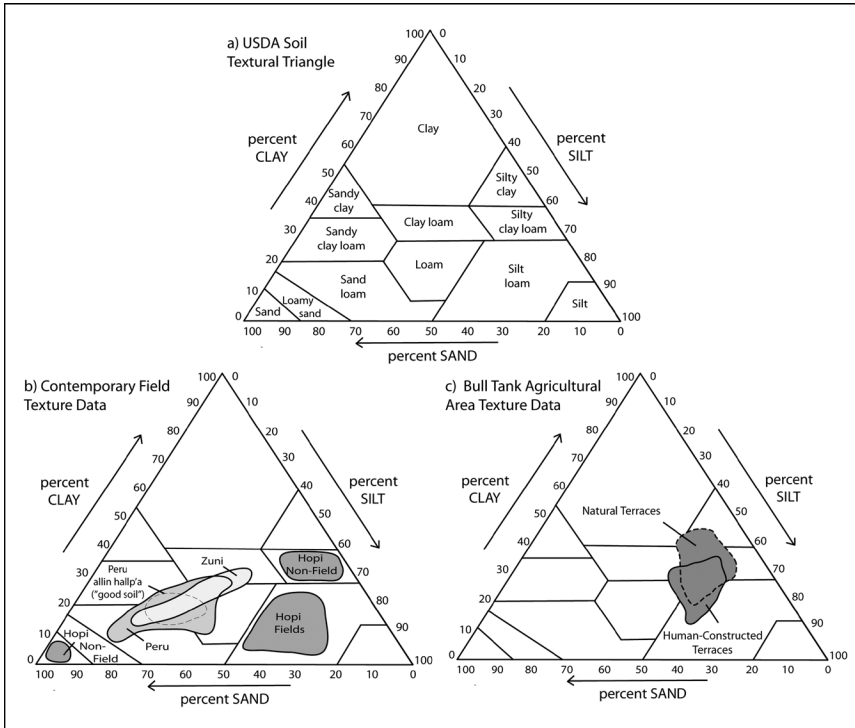


FIGURE 4. a) USDA soil texture triangle; b) data based on Dominguez and Kolm (2005:Figure 8) for Hopi fields and non-fields, Sandor and Furbee (1996:Table 2) for Peru soils, and Homburg and others (2005:Table IV) for cultivated and abandoned Zuni fields; c) based on 20 soil cores (0-7 cm depth) from human-constructed terraces within the Bull Tank Agricultural Area and 20 soil cores (0-7 cm depth) in a topographically similar area of natural geologic terraces.

shows that human-constructed terraces contain on average less clay than natural terrace locations (Figure 4). The primary ecological legacy left by humans on agricultural fields is thus an indirect one, caused by construction of rock alignments that subtly modify soil texture and water availability for primary producers.

Our data also show that Perry Mesa soils are generally higher in clay and lower in sand content than soils in other, more resilient agricultural locations that are still farmed today (Figure 4). The data in Figure 4 for the Hopi fields are taken from soil texture labels on Dominguez and Kolm's (2005) Figure 8: sand, silty clay loam, and silt loam. Note that the natural terraces on Perry Mesa contain the silty clay loam that Hopi farmers avoid, while the soils on human-constructed terraces are siltier, though not as much as the Hopi agricultural field soils. Data on Peruvian and Zuni agricultural field soil textures indicate a higher sand content than is typical for the Hopi fields that Dominguez and

Kolm studied. In both these areas, however, an impermeable substrate, such as an argillic horizon, holds the water at the plant-root level, thus ensuring the availability of water for crops.

To determine whether the texture differences that ecologists have documented on the Perry Mesa landscape today are the result of prehistoric agricultural terraces, archaeologist Melissa Kruse-Peebles has focused her research on investigating the sediment loads transported by surface runoff generated during intense precipitation events (Kruse-Peebles 2013). During the 2009–2010 summer and winter rainy seasons, runoff generated within terraces and off-terrace locations was collected within the Bull Tank field system. Measurements of the sediment load and texture indicate that runoff moves significant quantities of fine sediment particles (clays and silts) within terraced locations compared to off-terrace locations, where very little sediment is transported. This difference likely resulted from the higher density of surface rock in nonterraced locations, which slows runoff flow. The terraces are small, with an average cleared planting surface of just over 1 m. This small planting surface size limits the erosive potential of runoff events so that only fine particles are moved, not heavier sand-sized particles. Through the clearing of rock to create terraced fields, the people of Perry Mesa were able to increase the fine particle erosion via runoff within planting areas, removing the excess of clays. The runoff would have been controlled enough, however, that the coarse particles remained. This process is still occurring 700 years after the region was abandoned. This modification of soil texture would have led to more arable soils and made terraced locations conducive to farming.

Complementary data on the nutrient concentration (nitrogen) runoff indicate that the gradual movement of fine particles and organic matter downslope enhanced soil fertility within terraced locations (Kruse-Peebles 2013). During the era of prehistoric farming the nutrients contained in runoff would have prolonged farming for a few seasons by offsetting nutrient extraction from growing maize. These runoff processes still occur today and the continued control of runoff flow via terrace construction and field clearing can help to explain not only the documented differences in soil texture but also the nutrient and plant biomass differences between terraced and off-terrace locations on Perry Mesa (Kruse-Peebles et al. 2010; Trujillo 2011).

CONCLUSIONS

Farmers remained on Perry Mesa for probably not much more than a century, while people have been farming the Hopi Mesas for more than 2,000 years. One implication of the distinct differences in soil textures of these two areas, then, is that, in the absence of suitable soil texture or the addition of substantial quantities of nutrients such as nitrogen from runoff or other sources, long-term rain-fed agriculture is not viable in southwestern upland locations such as Perry Mesa.

But why had farmers moved to Perry Mesa at all? An answer to this requires a larger-scale understanding of climate dynamics at the time of the Perry Mesa occupation. In another Legacies project investigation, Scott Ingram (2014) found that the timing of Perry Mesa immigration in the late A.D. 1200s coincided with a higher-rainfall, pluvial period. Ingram's (2010) doctoral research has demonstrated that this migration was part of a larger process. During the late 1200s and early 1300s many southwestern landscapes that had been largely unoccupied experienced significant immigration because there was more secure precipitation in these locations than in areas where people had previously lived for centuries. By the early 1400s, however, climate in these areas had deteriorated, and people abandoned their settlements and moved elsewhere. It is thus likely that synergies between increasing drought and the challenges of farming Vertisols led to the depopulation of Perry Mesa in the late 1300s or early 1400s.

Through a diversity of analyses, the Legacies project is engaging the question of whether prehistoric human activities are the drivers of contemporary landscape processes on Perry Mesa. Although the ecological literature clearly shows that the legacies of disturbance likely differ depending on vegetation type, population dynamics, and speed of nutrient cycling through ecosystems, only a few studies have focused on the long-term ecological legacies of human action in slow-growing arid land systems like those in the Southwest that take centuries or more to develop (Briggs et al. 2006). Taken together, our ecological and archaeological data suggest that the long-term ecological legacies of prehistoric farming on Perry Mesa are subtle and largely derive from the persistence of humanly constructed terraces on this landscape. Our research has also contributed to an understanding of agricultural sustainability in the Southwest. Although Perry Mesa was an attractive destination for farmers under conditions of increasing drought in the late 1200s, Perry Mesa soil texture would have presented challenges. Farmers were able to address these challenges through terrace construction but would have had to let fields lie fallow for some years once soil nutrients were depleted. Perry Mesa had enough land to accommodate farmers shifting field locations every few years (Kruse-Peebles 2013), but the labor involved in maintaining terraces on fields in fallow (to accumulate nutrients) and those on fields in cultivation may have proved too much. In the end, along with many other southwestern populations, the residents of Perry Mesa left for much better watered, more arable locations.

AUTHORS' PUBLIC DISCLAIMER

This work is not a product of the United States Government or the United States Environmental Protection Agency, and the author is not doing this work in any governmental capacity. The views expressed are those of the author only and do not necessarily represent those of the United States or the U.S. EPA.

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Repairing the Damage

Reforestation and the Origins of the Modern Industrial Tree Farm

“Advanced deterioration usually precludes profits,” observed Aldo Leopold in 1934 (Leopold 1934: 541). Some of the most important New Deal conservation programs had been passed the year before, including measures meant to compel lumber companies to ensure regeneration of forest cover following logging on their own private lands. Conservation on public lands might be less complex to ensure, but without a simultaneous effort on private lands the process would be greatly hindered. Leopold put it bluntly: “whenever a private landowner so uses his land as to injure the public interest, the public will eventually pay the bill” (Leopold 1934: 541). This effort faced less reluctance from larger lumber companies than some conservationists predicted. Spurred by threats of New Deal regulation and worries about economic stability, some lumber companies in the Pacific Northwest developed a voluntary regeneration program suited to their interests: the industrial tree farm. The development of the tree farm mode of private-lands reforestation was a direct result of the reframing of the federal debate over land conservation during the New Deal. This development has been neglected by historians and others, despite its large ramifications for forestlands across the nation and around the world.

The divergence of industrial reforestation from mainstream Leopoldian ecological restoration has been wide since the passage just quoted was written. This essay looks at the construction of the first industrial tree farm as a turning point in the history of land regeneration. It marked the crystallization of a new rhetoric, a new scientific agenda, and a new economic approach to repairing degraded industrial forests. By tracing the path the lumber industry took in this divergence one can discover new context for the language and practice of restoration and regardening practices. Showing the contingency of past decisions made in the design and conception of industrial tree farms allows a new understanding of postlogging landscapes.

While the first American tree farm was on its face a reaction of the lumber industry to New Deal conservation, the motives those involved in its creation expressed are quite complex. Attempts to stop destruction of natural forests by designating untouchable wilderness areas, hindering logging leases in the national forests, and regulating logging activity on public lands threatened to greatly curtail the lumber industry's activities. Wilderness advocates generally disregarded those areas already logged, but lumber companies could now point to their work in tree farming to underscore their commitment to the long-term persistence of the Douglas fir forests. Many academic and government foresters, as well as environmentalists, viewed the lumber industry's adoption of the tree farm concept as a cynical ploy to influence public opinion and stave off regulation (Brock 2015, 2004).

Contemporary players in the global lumber industry present tree planting as restorative, as an appropriate response to logging damage. The public relations campaigns of such companies highlight the renewal of the harvested trees and the maintenance of the long-term health of the forest. Industry claims about the restorative effect of these plantings are often viewed skeptically, but whether or not these plantings approach real restoration we should not ignore them. Given the size, scope, and potential of the activity the forest industry has undertaken on its own lands, to disregard it would be imprudent. Understanding the motivations and origins of industrial tree farming and placing that effort on the spectrum of restorative land use is valuable to understanding forests health (Prudham 2005; Floyd 2002; Best and Wayburn 2001; Hirt 1994; Clepper 1971).

Understanding the history of cultural activity on a landscape, whether that activity is degradation, maintenance, or repair, is valuable in determining contemporary approaches to that landscape. Planting and management decisions made in the earliest days of tree farm design are significant for understanding the cultural and ecological patterns of Douglas fir forests in the contemporary Pacific Northwest. The long growing period for Douglas fir means that seedlings planted in the 1940s are only now reaching maturity. Current efforts to restore degraded second-growth forests can benefit from knowledge of the cultural and scientific basis of past decisions (Higgs 2003).

While excluding such important ecological elements as wildfire, the earliest American industrial tree farms were nonetheless meant to approach the prelogging natural forest. The forest ecology of the Cascade and coastal areas of the Northwest is highly diverse, but in cultural and economic terms it is dominated by a single tree species, the Coastal Douglas fir (*Pseudotsuga menziesii*). The second-tallest species of tree in the world, mature Douglas fir regularly reaches 250 feet in height and 6 or more feet in diameter. Because the tree is so large and grows relatively densely, the yield of lumber per acre in the region's old-growth forests was the highest seen in any American forest. Following the bust

of the Upper Midwest lumber industry at the end of the nineteenth century, several of the largest lumber companies moved to the Northwest, their sights set on the promise of the Douglas fir. The rugged terrain and high cost of operations in the region meant that the lumber industry quickly became reliant on clear-cutting regimes to bring timber to market. As a highly lucrative market for Douglas fir framing timber developed, the maintenance of a viable industry became of paramount importance to the region's economy. State-level attempts at public regulation of postlogging industrial land use reflected the importance of a stable lumber industry to the region as early as the 1920s. The motive in the region's early industrial reforestation was not just to replace the forest resource but to replace the lucrative Douglas fir species in particular (Robbins 1999; Williams 1989; Franklin and Dynes 1988; Robbins 1982).

The lumber industry of the Pacific Northwest came to tree farming after a number of years of trying other, less complex methods of forest regeneration. Unaided reversion to forest of abandoned clear-cut lands in other parts of the United States suggested a similar process might be possible in the Douglas fir region. The physiological parameters of this species, the unique Northwest climate, and the harsh topography of the clear-cut sites rendered this impossible. Attempts to instigate low-cost seminatural regeneration of Douglas fir on clear-cuts in the 1910s and 1920s resulted in poor or nonexistent reforestation. After these failures, industry insiders and observers alike acknowledged that regenerating lands after logging would be an exceedingly difficult and expensive undertaking. The consensus by the 1930s was that reliable large-scale reforestation of the species would require hand-planting of seeds or seedlings, liberal use of poison and trapping, and vigilant fire protection, all made more difficult by the region's rugged terrain (Brock 2015, 2012; Goodyear 1939; Munger n.d.). Despite the initial expense, in the long run artificial reforestation was the only method for successful Douglas fir reforestation on clear-cut land. These costs were not welcome news to the forestland owners and state agencies interested in Douglas fir reforestation. However, several large lumber companies did have both the desire and the wherewithal to accomplish this task. Foremost among these was the Weyerhaeuser Timber Company.

WEYERHAEUSER'S CLEMONS TREE FARM

The first industrial tree farm, the Clemons Tree Farm, was established on Weyerhaeuser Timber Company land in Grays Harbor County, Washington, in that state's Coast Range. Logging operations had been established there for a number of years, and by the late 1930s saleable timber on the land was almost entirely gone. In 1938 and 1940 two large fires swept through logged-off areas of this parcel, both reducing the chances of natural reforestation on that acreage

and requiring emergency outlays of money for firefighting and recovery. The Weyerhaeuser Reforestation and Land Department, assessing the economics of fighting forest fires, determined that if the company had spent the same amount of money on fire prevention that it spent on recovery from those fires the entire Clemons area could have been almost completely saved. It concluded that the investment of large amounts of money in fire prevention was the most economical way of preserving the value of the young growing trees over the long term (Brock 2012; Hidy and Evans 1963; Sharp 1949; Tilley 1944; Grogan 1943; Price 1941). In order to pay for this level of fire protection, however, the Weyerhaeuser accountants stipulated that the area under protection needed to be fully stocked with growing Douglas fir. Given the large monetary investment for fire suppression, the eventual payoff in lumber sales had to be virtually certain. Natural reforestation, although very inexpensive, was too slow and too unpredictable to use in such a venture. Furthermore, the degradation of the site meant that on much of the Clemons Tree Farm reforestation by natural means was unlikely to ever occur. To make the fire protection system cost-effective, intensive artificial reforestation had to be undertaken in order to furnish something of value to be protected from fire. Establishing the infrastructure for the Clemons Tree Farm would involve a large investment of corporate funds (Clemons Tree Farm 1941). An internal Weyerhaeuser history explained that the “plan was based on fully stocked land. Unless we had fully stocked land to protect, such an expensive system was not feasible; therefore, plans for restocking, by planting all denuded area was included” (Grogan 1943).

While tree plantations had existed in Europe for centuries, European antecedents differed greatly from their American counterparts in ecological factors, management philosophy, and economic parameters. Scattered nineteenth-century tree plantations and the Civilian Conservation Corps’ 1930s replanting projects in the Northeast and the Midwest differed enough from the newly conceived tree farm that the Weyerhaeuser Timber Company could not extrapolate much from them about their own project’s potential. Weyerhaeuser Timber Company executives realized that the supply of virgin timber in the United States could not last forever. Instead of diversifying the company’s interests into industries and markets that were not so closely tied to a dwindling supply of natural resources, Weyerhaeuser intensified its focus on forest products while broadening its base within that industry. At that time the company was not publicly traded and thus had no hence need to see profits accrue quickly for the benefit of stockholders’ short-term dividends. The executives deemed economic stability and consistency of production far more important attributes than diversification, speedy growth, or short-term profits (Brock 2015, 2012; Williams 1989; Illick 1927). The Clemons was a site with two explicit long-term goals, which were assumed to be compatible: the industrial-scale production of

timber and the rigorous study of methods of artificial reforestation. Since all logging operations on the Clemons lands were completed and the land had been designated as unproductive and essentially worthless, company foresters could be given free rein to experiment on the Clemons Tree Farm. While most of the reforested acreage would be planted according to the most reliable methods, company foresters hoped to use some of the land to conduct a number of long-duration reforestation trials using different treatments and planting patterns. Forestry research would center on perfecting artificial reforestation techniques for Douglas fir that could be used both at that site and at future tree farms. Planned research concerned planting approaches on different kinds of terrain, the possibilities of soil fertilization, disease and insect prevention, pruning and thinning regimes, and Douglas fir population genetics (Brock 2015, 2010, 2004; Prudham 2005; Sensel 1999; Rajala 1998; Hidy et al. 1963; Winters 1950).

Weyerhaeuser claimed the tree farm as the perfect place for “a centralized research program to supervise and coordinate the collection of necessary data and information, and to sift out, supplement if needed, and make available with necessary recommendations, the pertinent information gathered by private and public agencies engaged in forestry and forest-products research.” It saw the most promising areas for study at the Clemons as “rodent control,” “improved planting practices,” “direct seeding,” “fire danger rating,” and “development of markets for minor forest products” such as red alder and other brush species (Donaldson and Grogan 1942). While some areas were left to reseed from the few nearby standing trees that remained, most of the regeneration involved labor-intensive artificial reforestation. With seedlings from their Longview, Washington, nursery, teams of laborers replanted Douglas fir following a variety of methods. Further experiments in rodent control and thinning of seedlings were planned for the young trees as they grew. The activities on the Clemons acreage were closely monitored by Weyerhaeuser employees and were planned to last for decades. Thus, the results of the planting trials would be far more reliable than many previous industry experiments in reforestation had been. From the beginning Weyerhaeuser was conscious of potential public cynicism about its commitment. Through emphasizing control and scientific approach it aimed to convince the region that its new venture would be both permanent and profitable (Brock 2015; Tilley 1944).

What did the Weyerhaeuser Timber Company hope to gain from the Clemons Tree Farm? Neither the company nor its officers made any pronouncements about their expectations for the profitability of the Clemons Tree Farm at the time of its inception. The monetary investment in the Clemons tract was not very significant, and the company did appear to value its short-term public relations benefits as much as its eventual long-term profit potential. The company stated that “Under favorable circumstances, which are attainable, privately

owned forest lands can be managed to produce successive forest crops on a profitable basis, if coupled with public understanding and cooperation. At the present time public understanding lags behind the actual deeds of private land owners. Therefore, informing the public of our progress is an obvious responsibility. To do this it becomes essential to have definite measuring plots—areas upon which facts can be obtained, and where those facts can be demonstrated through visible accomplishments. The first such demonstration area of our company is [the Clemons Tree Farm]” (Weyerhaeuser Timber Company 1941). The Clemons Tree Farm was a small demonstration project, but one that had the potential to determine company practices and policies for the long term. The Clemons, while both innovative and complex for those involved in its formation, was small in scope in terms of the Weyerhaeuser Timber Company’s landholdings and finances (Brock 2015; Tebbe and Andrews 1949).

Weyerhaeuser wanted to ensure that the Clemons fulfilled its promise not only as an experiment in permanent forestry but also as a public relations tool. The research and experiments conducted at the site were exploited on the public stage to inspire trust in the undertaking. Roderic Olzendam, the Weyerhaeuser Timber Company’s head of public relations, envisioned the event as an experiment in public relations, calling it “very promising. . . . I am hopeful that we can demonstrate that the people of the community will rally with enthusiasm and real interest around the constructive program of a private corporation” (Olzendam 1941a). The total costs surrounding the dedication and its advertising were sizable for a ceremony that promoted simply the Weyerhaeuser name without actually marketing any products or services. This was, to a large extent, a public relations spectacle to convince the public that Weyerhaeuser had people’s best interests at heart. In the short term, the Clemons Tree Farm would be a well-managed, fire-free, taxpaying neighbor. In the long term, the Clemons Tree Farm would supply work to the area’s loggers and prove that the Douglas fir lumber industry was a permanent presence in the Pacific Northwest (Olzendam and Keith 1982; Clemons Tree Farm Advertising 1941).

In describing the Clemons, Olzendam evoked nostalgia for the dwindling old-growth forest and for the difficult work of earlier decades of logging. He acknowledged the profligate past, saying that “we lumbermen of Grays Harbor County certainly do not claim that our stewardship has been perfect—far from it. . . . Richly endowed by the Almighty with natural resources, we of this County, and of most other counties, all of us have used those resources, shall we say, profusely? We have had a pretty swell set-up here, probably a better set-up than we could afford to keep up permanently” (Olzendam 1941b). Replanting the clear-cut lands would allow not just regeneration of the forest but also maintenance of the Northwest’s culture and economy. He stated that “‘We the People’ of Washington, every last one of us, separately, and all of us

collectively—whether we fall or buck, saw or finish, teach or learn, enact laws or obey them, sell or buy, preach or practice, work or loaf, hunt or fish—each one of us has a personal forest objective. Each one of us wants to do something definite about our trees” (Olzendam 1941b). The needs and expectations of the citizenry, he asserted, could be met by the economic stabilization of the lumber industry through tree farming. While he acknowledged the importance of the existing national and state parks, he warned of the dangers of relegating any more forest land to recreation alone. If too much of the Douglas fir forest was preserved for recreation, he warned, Pacific Northwesterners would run the risk of becoming “a race of yodelers tripping around in feathered hats and slickers high among the ‘rain forests’; there is even a possibility that fallers and buckers will be transformed into nursemaids to tourists from Tennessee; that our high climbers will become caddies, and our head sawyers may be serving tea and sandwiches to sightseers” (Olzendam 1941b).

While public response to the economic potential of the Clemons Tree Farm was enthusiastic, the national response by academic foresters was much more guarded. Many expressed skepticism about its declared scientific foundation, its focus on agricultural metaphor, the tree farm failures in some European forests, and Weyerhaeuser’s long-term commitment to the project. Such concern was the topic of at least six *Journal of Forestry* editorials between October 1941 and December 1943, became an active subject of debate among professional foresters, and was reflected in Aldo Leopold’s famous “Land Health and the A-B Cleavage,” in *Sand County Almanac* (Leopold 1949: 258–261). Despite such criticism, the industry used the Clemons as evidence of a first step toward coming back into a realistic rate of consumption in the Douglas fir forest, a rate that could be maintained permanently. In conjunction with the dedication of the Clemons Tree Farm, in 1941 the lumber industry’s main trade group set up a tree farm certification program, which continues to the present. Tree farm designation was conferred nationwide on private land already under reforestation management as well as on new plantings on deforested lands (Brock 2015, 2012; National Forest Products Association 1947; Rogers 1944).

THE TREE FARM IN THE CONTEXT OF REGENERATION

As seen elsewhere in this volume, the potential for restoration and conservation on landscapes recovering from human impact is both important and highly complex. Though they are not by any means untouched or original forest ecosystems, sites planted as tree farms still hold the potential for partial ecosystem recovery. Although Weyerhaeuser never claimed the Clemons Tree Farm would be a re-creation of the original forest, there were still both immediate and long-term ecological benefits to its creation. The replanting of tree cover on clear-cut

areas slowed soil erosion, protected streams from silt runoff, and provided continued structure for wildlife habitat. In the eyes of its custodians the landscape had not changed irrevocably in its passage from natural forest through clear-cut to tree farm, even as the changes eliminated many of the land's key features. Though the ecosystem was simplified and strictly controlled, the recovery potential was not lost as it was in areas planted with exotic species or transformed for agriculture or other uses. Indeed, if managed for ecosystem restoration rather than for wood production, second-growth can be the site of an array of rare and important species (Apostol and Sinclair 2006; Mansourian et al. 2005; Wells 1999; Sauer 1998; Drengson and Stevens 1997; Kimmins 1997; Noss 1994; Pimentel 1993; Norse et al. 1986).

Clearly, the industrial tree farm was not meant to create a continuous forest ecosystem but rather was intended to serve as a continual forest resource—interrupted by periods of logging. The Clemons stands as an integration of forestry and lumbering that promised both future lumber yields and a partial restoration of ecosystem function. Advocates aimed to stop net loss of forests by regenerating lands already damaged by logging. In its rhetoric as well as its methods, tree farming was a marriage of the lumber industry's practical needs with professional forestry's desire to curtail forest destruction. Importantly, this effort took place on privately owned lands, as lumber companies experimented on their own lands with reforestation of their own clear-cuts. While the founders of the first industrial tree farm valued their work differently, the work of a tree farm is still similar to the work of restoration. Creating a tree farm meant restoring some ecosystem processes, not to establish an intact forest ecosystem but to regain those aspects of an ecosystem that most appealed to the land's users. In both industrial reforestation and ecological restoration, the recovery of certain species is privileged, and the health of the rest of the system is addressed through that prism. With ecological restoration the recovery of rare or emblematic species is often an indication of success, while on a tree farm the viability of a commercial lumber tree is generally the goal. Restoration following the eruption of Mount St. Helens provides an interesting case of the intersection of these two goals (Franklin et al 1995).

The industrial tree farm's partial repair of a deeply damaged landscape occupies an intermediate place in the spectrum of restorative land use. George Perkins Marsh described the utilitarian goal of transforming a deeply degraded landscape into one that is modified and designed especially for optimum human use. This approach, recently termed "reparative gardening," was first described by Marsh in 1864 as a response to human degradation of a natural landscape that entails the creation of an idealized, seminatural landscape. While most contemporary restoration seeks to create a healthy ecosystem, the first tree

farms intended to repair the damaged landscape only partially. The creators of the early industrial tree farms coupled Marsh's conception of reparative land use with the utilitarian policies Gifford Pinchot laid out for forest use. Pinchot viewed natural forests as resources to be used by American industry, so it followed for many in industry that, following logging, the denuded land itself would hold potential for further use as the site for a future crop (Hall 2005; Lowenthal 2003; Miller 2001; Marsh 1965).

Industrial tree farms differ from other forms of ecosystem repair because they are not rooted in environmentalism. The reconstruction of the forest is not being done primarily for the sake of that ecosystem's inherent value. The stated goal was not the permanent reemergence of a healthy ecosystem but rather the temporary regaining of the dominant tree species in order to facilitate a future harvest of lumber. Even at the beginning, tree farming differed in fundamental ways from what contemporary ecologists would call restoration. As a process taking place on private lands, the reforestation efforts of the early tree farms stand in contrast to most other efforts to restore ecosystem function. While large-scale nature preservation on private lands has been common for more than a century, tree farms are a rare historic example of large-scale repair efforts on private lands. Examining tree farms through the prism of restorative land practices can lead to new insights about both industrial forests and contemporary restoration. Many cases exist of proposed and active large-scale restoration projects on private lands (Donlan et al. 2006; Foreman 2004; Davis 1998) and of private restored and sustainable forests managed for profit, not preservation (Jenkins and Smith 1999), as well as of large-scale preservation on private estates (Schenck 1998; Schneider 1997; Robbins 1999; Best and Wayburn 2001).

The term "sustainable forestry" first became prevalent following the 1992 Earth Summit in Rio de Janeiro. From this beginning, sustainable forestry has been connected to the regeneration of forests and to large-scale tree planting (Brock 2014; Sedjo et al. 1998). The Rio statements on forestry declared that "efforts to maintain and increase forest cover and forest productivity should be undertaken in ecologically, economically and socially sound ways through the rehabilitation, reforestation and re-establishment of trees and forests on unproductive, degraded and deforested lands, as well as through the management of existing forest resources" (United Nations 1992). In 1994 a consortium of American forest industry representatives established the Sustainable Forestry Initiative (SFI), declaring it the industry's voluntary and direct response to the statements at Rio. The SFI provided an impetus and an administrative framework through which its lumber industry partners could provide for the reforestation of vast areas of American landscape affected by logging (Hays 2007;

Cohen 2004; Cashore et al. 2000; Franklin 1993). Carbon offset planting, the attempt to offset carbon emissions and combat global warming through large-scale tree planting, has brought new interest and scrutiny to large-scale reforestation. Advocates of carbon offset planting present it as a dual benefit—a way to repair human-caused damage to the global climate and to correct human-caused loss of global forest cover. However, critics point out that such plantings are often undertaken with little real foundation in either climate science or forestry. Envisioning tree plantations as carbon sinks is a new chapter in the long story of privately funded large-scale reforestation (Bocking 2004; Royal Society 2001; United Nations 1992).

Most of today's American industrial tree farms differ greatly from natural forests. Sometimes voluntarily, sometimes compelled by law, the industry has established industrial tree farms on many postlogging landscapes. In the past 50 years industry has developed techniques to grow trees quickly and to use younger trees in paper and wood products. The Douglas fir region's tree farms differed significantly from tree plantations elsewhere in which the native forest, once logged, has been replaced with exotic commercial species. Contemporary rewilding efforts in the Douglas fir region may be less likely to encounter exotic tree species dominating the degraded ecosystem, a problem for similar efforts in other forested regions (Carrere and Lohmann 1996; Marchak 1995).

To conclude, industry has asserted that its tree-planting efforts are reparative despite disagreement from many within mainstream ecology. The beginnings of the American lumber industry's relationship with intentional reforestation, in the inception of the first American tree farms, show the deep roots of this rhetorical stance. It is important to consider the place of industrial restoration of private lands within the full spectrum of restorative land use. Scholars of restoration should not overlook the work of industrial reforesters simply because they do not have the same values and goals as mainstream restorationists. Industrial tree farms are not inspired by environmentalism; the values behind them are based more in economics, public relations, and politics. Not only are the motives of industrial reforestation projects different from those of mainstream restoration, but also the goals of these two groups are different. While mainstream restoration seeks to create a stable ecosystem, the industrial tree farm, in its very essence, has a different endpoint.

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Sustainability, Resilience, and Dependency

The Great Plains Model

Over the past 400 to 500 years, the Great Plains have seen a rapid succession of ecological regimes. The ecological historian Dan Flores has written that plains ecological history “centers around a series of ecological crashes and simplifications.”¹ This text attempts to give an overview of these successive ecological systems and to provide an analysis of the lessons in sustainability, resilience, and ideology offered by the plains ecological history of the past few centuries. The plains, a semi-arid ecosystem, have “fewer of the safeguards built into more diverse systems.”² Because natural resources “in semi-arid countries are often set in a hair-trigger equilibrium,”³ the plains can serve as a good model for issues of sustainability and resilience elsewhere. Many historical and ethnographic studies have looked at human-bison interactions, hunter-gatherer lifeways, and Native agriculture on the plains. Agricultural, wildlife management, and grasslands research have both led to and engaged with the industrial ecosystem that has become imposed on the plains. Ecological approaches have also been used to discuss sociological consequences and political proposals for this vast region. This is not a detailed study, and I can do no justice to the broad literature: my focus will be on what the plains can teach us about sustainability.

Sustainability and resilience are two popular concepts, although or perhaps because they are difficult to define and even more difficult to apply. The difficulty with both stems from their connection to change over time, as well as an approach to ecology that sees human involvement as an unnatural, outside influence on ecosystems. Resiliency, the ability to withstand impacts without transforming the nature of the system, can serve as an example. It is almost impossible to note whether or not a given ecosystem is resilient, as “an ecosystem that is not resilient will appear unaffected by until a critical threshold is passed.”⁴ Thus, any ecosystem that appears resilient (and sustainable) might simply be approaching a catastrophic threshold; on the other hand, unless that threshold is reached and the ecosystem is changed, nobody knows that the system is not resilient. Sustainability is often simply relative sustainability, as it is

impossible to determine exactly when, why, and how an apparently sustainable system, dependent on a large number of variables, became unsustainable. If a given ecosystem, such as the plains, is undergoing a series of relatively rapid changes, estimates on sustainability and resilience of these systems become impossible because the systems are not allowed to play themselves out. The historical measurement of sustainability and resilience is almost by definition limited to the observation of whether local populations change their subsistence strategies, so that in the absence of a catastrophic event or the adaptation of new cultural ideas sustainability lasts as long as discernible change is avoided. Ideological resilience thus enters the equation because cultural resistance to change can make an ecological regime appear sustainable while at the same time preventing the flexibility that might avoid a catastrophic failure.

In discussing the sustainability and resilience of subsistence strategies, we also have to avoid “neat presentations in ecology textbooks that endeavor to contrast the ‘harmonious’ and ‘intuitively ecological’ human-environment relationships of indigenous people with the wholesale destruction of nature by modern industrial societies.”⁵ This reminder might be of importance to ecologists and others who believe in Frederic Clements’s climax theory, which stipulates that the plains had existed in some sort of natural balance, undisturbed by human hunters, who took their place among the other species, until “abruptly and violently it was destroyed, not by any vast impersonal change in climate but by the invading white man.”⁶ Neither the presence of the “white man” nor the presence of agriculture is a sufficient factor to explain the ecological changes that became imposed on the plains, however. Some authors see the presence of modern humans in itself as an unsustainable impact on ecosystems.⁷ If this is true, we have to either give up on achieving sustainability or exit the planet. It is true that there is no original habitat left: “All habitats, biomes, environments have been under continuous transformation by human beings and other species.”⁸ But then, there was never any original habitat that could have been restored. This does not mean that we should simply give up on conservation and sustainability. However, the idea of wilderness in the sense of untouched nature is an obsession that is most pervasive in settler societies that, for romantic and colonial reasons, ignore indigenous ecosystem uses.⁹ It seems somewhat curious that natural unsustainability is often simply perceived as ecological change; it is often only human ecological approaches that are taken to be unsustainable. This approach takes humans out of ecosystems, where they belong so that they can and must take full responsibility for their roles within their environments.

The variety of human ecological approaches to the plains can be generalized to a series of cultural changes. Pedestrian and, later, equestrian hunting and gathering coexisted with horticultural societies; these were largely replaced by cattle ranching. While ranching stayed, especially in the western areas, a version

of European yeoman agriculture was introduced; this was replaced by industrial agriculture, including industrial ranching. Although the plains are today one of a very few areas in North America where agriculture forms the backbone of the economy, in certain areas tourism and suburban or exurban developments have replaced it as the most important ecological and economic activities. Frank Gilbert Roe wrote that an "attitude of virtual despair . . . prevailed among scholars" who cannot pinpoint when, where, and how exactly Indians procured horses and developed horse cultures.¹⁰ Such questions are not my preoccupation here; instead, I will try to discuss whether these different ecological approaches were sustainable and how resilient they were, both ecologically and ideologically. It is important to keep in mind that none of these predominant economic strategies has ever been pure; while Preston Holder wrote that the hoe and the horse "represented fundamentally different accommodations to the environment of the Plains,"¹¹ all of these subsistence activities could and can occur simultaneously in a given society.

Pedestrian hunter-gatherer and horticulture regimes seem to have been relatively sustainable and resilient. This perception, however, might be a consequence of our limited knowledge of changes in these cultures, which appear in archaeological horizons that can tell us very little about changing ideologies, techniques, and regimes of resource exploitation. If populations remained hunter-gatherers for thousands of years, we assume that their subsistence strategies were both sustainable and culturally resilient, although we most often cannot know the details of their "ecological experience" or of their "ecological behavior."¹² Also, since the environment did not seem to change too much or at least not very quickly, we assume that it was resilient. A closer inspection, of course, reveals that the ecosystem 10,000 years after hunters and gatherers appeared on the plains looked very different from the way it was earlier, both because of new pressures and climate changes and because the original ecosystem was impossible to reconstruct. The plains were, from that perspective, not very resilient. The determination of ecosystem resilience thus rests on the time period chosen for evaluation.

It is fairly clear that the succession of changes in the plains ecosystem accelerated after the appearance of new societies unfamiliar with the system, yet very sure of their ecological ideology.¹³ The first, indirect consequence of the European influence on the ecosystem was the introduction of the horse, which transformed hunting and gathering on the plains from a marginal endeavor to a very attractive lifestyle. The reliability of the bison as a resource for the horse cultures, even for the agricultural nations on the plains, led to the development of vibrant, dynamic, and powerful cultures. It also led to an influx of people into the ecosystem, an increase in hunting, and competition for grass through the large horse herds. The horse cultures were still very young when they were

destroyed by the American invasion of the plains. Because the new ecosystem was forcefully aborted through the mass slaughter of the bison and because it had existed for only about 200 years, it is difficult to establish its sustainability. Andrew Isenberg has argued strongly that plains Indians engaged in the robe trade were already destroying the bison.¹⁴ Dan Flores explains the Siouan expansion westward by the continuous depletion of that resource.¹⁵ Even if these views point to an unsustainable ecological regime, we cannot know, of course, whether plains Indians would have adjusted to the diminishing resource. The Lakota and others seem to have developed a notion of bison herds as group property, to be protected from disturbances, at least by others. The question whether the indigenous use of bison as a resource for international trade was sustainable will never be solved, since the American bison hide hunters put an end to the bison as a resource. The emphasis on the importance of buffalo on the plains obscures another question, of course: given that the bison were temporarily destroyed, did that mean the end to the ecosystem as it had existed? The answer to this question is still hotly debated because it is directly linked to an evaluation of one of the successor ecosystem on the plains: cattle ranching. While the question of sustainability of American Indian ecological regimes is used to present a picture of either historical progress or ecological regress,¹⁶ the sustainability of ranching is a contemporary political debate.

Much of one side of that debate was lined out by Walter Prescott Webb in 1931. He assured his readers that cattle ranching on the plains was a natural and logical endeavor once "the buffalo and the Plains Indians . . . together passed away."¹⁷ The cattle kingdom, as Webb calls the complex economic and political forces of early ranching, "arose naturally out of conditions peculiar to the setting."¹⁸ Cowboys, whom Webb portrays falsely as "the first permanent white occupant[s] of the Plains," were without the supports of civilization and therefore made a "perfect adaptation" to nature. Cattle herding, from this perspective, "was conditioned by environment. It was a natural occupation which used the land in its natural state and altered it hardly at all."¹⁹ Ranching can thus be positioned both as a nonintrusive ecological regime and as a supposed romantic and evolutionary scheme that leads to agriculture. Unfortunately, this view ignores most ecological facts, except that both bison and cattle eat grass.²⁰ However, that ranching changed and is changing the ecosystem does not necessarily make it unsustainable. Most advocates and opponents of ranching are focusing on the ways in which cattle are ranched, not ranching's existence as such,²¹ and so the discussions focus especially on whether the range is overgrazed. The concept of overgrazing is older than the one of sustainability, but both express the same idea, namely that resources are overused. Both terms also encounter the same difficulty: without agreement on what normal or sustainable resource use means, they are almost meaningless. Cattle grazing has changed the grasslands.

Nonnative plants have been spread, different pressures are being exerted on certain parts of the ecosystem, such as riparian areas, and the selection of grazing plants has been altered.²² John Bennett points out, however, that the brush cover resulting from overgrazing increases the biomass. "Humans," he writes, "consider it to be a deleterious change for economic not ecological reasons. The case illustrates the tendency for judgments about ecological matters to become intertwined with human purpose and values."²³ Cattle and their economic, symbolic, social, and political consequences have changed the ecosystem of the plains in profound ways, just as horses did earlier. To conserve any ecosystem in a given state, however, would not be natural, either. The difficulty of determining sustainability and resilience lies in allowing but limiting ecosystem change. The hardest task is finding the appropriate rate.

While ranching replaced the horse/buffalo ecological regime in the western plains, the eastern plains became more and more intensively farmed. Agriculture had been present on the plains for at least 1,000 years; it was thus the intensification of the practice that changed the ecosystem, as well as the geographical extension away from the river valleys. Early efforts to extend agriculture into the western, more arid shortgrass regions met with disaster in the 1880s: Turner called it the "first defeat" for the "native American farmer."²⁴ The droughts and harsh winters of the 1880s showed that the agricultural and ranching methods used were not adapted to the climate and soil conditions of the plains. The methods used were not sustainable, and evidence for this can be seen in the ensuing population decline. It was the growing industrialization of agriculture, especially, that allowed for agricultural settlement.

Geoffrey Cunfer argues that American agriculture was never ecologically sustainable. Farmers continuously "opened new land, cropped it for several decades as fertility declined, and moved westward to plow richer soil on new frontiers."²⁵ They applied swidden agriculture on a huge scale, without ensuring that their old soils recovered. After the frontier closed and no new soils were available, farmers "appropriated abundant, cheap fossil-fuel energy to import enormous amounts of synthetically manufactured nitrogen onto their fields."²⁶ Turner had made the same argument about unsustainability, but in economic terms, 100 years earlier: the western advance, he wrote, was fueled by economic ruin and the availability of "the farther free lands to which the pioneer could turn."²⁷ The availability of land for settlement, especially but not only through the Homestead Act, led to an unsustainable population density because the resources in the semi-arid and arid regions of the plains were scarce. Whether homesteading was a "magnificent failure" rests on one's perspective, but it was a failure for the majority of those who attempted it in the West.²⁸ Bennett notes that only 20 percent of first-time homesteaders on the northern plains stayed on that land.²⁹ Depopulation is and was, of course, tied not only to ecological

but also to economic sustainability. This becomes obvious when one considers not only the Dust Bowl years but also the farm crises of the late twentieth century. With the increasing industrialization of agriculture and the rise of postindustrial service industries, the alienation of people from their ecosystems has reached a point that ecological sustainability has been perceived to be less important. The depletion of the aquifers and the looming end to the supply of cheap fossil fuels will change this in the future, but the late twentieth and early twenty-first centuries have seen the imposition of ecological regimes that are driven almost purely by economic concerns.

Agriculture and ranching are not *per se* ecologically unsustainable on the plains. While the old tallgrass ecosystem, especially, has almost disappeared,³⁰ the plains are very resilient. The problem with ecological degradation on the plains lies less in the amount of land that has been plowed and grazed by cattle and more in the fragmentation of the ecosystem that has resulted.³¹ Cunfer writes that “there is a reservoir of natural diversity in the Great Plains that co-exists with the modern agricultural system,”³² and Licht asserts that “agriculture, even at its present level of production, and the long-term conservation of grassland biodiversity are both compatible and achievable.”³³ Indeed, the remaining patches of the old ecosystem can be used for expansion and restoration, if appropriate policy steps are taken to support this.³⁴ Restoration and conservation of landscapes, if not taken literally, can go hand in hand with sustainable use of resources, adapted to ecological circumstances: bison ranching, for example, is seen by many on the plains as a pathway to restoring ecological resources while also offering economic opportunities.³⁵ Thus, when Leonardo Boff states that “sustainable development is an oxymoron,”³⁶ he means not that sustainable use is unachievable but that the “prevailing type of development is not really compatible with ecological ideals, because it is based on the exploitation of nature and human beings.”³⁷ Such exploitation can best be shown and seen in marginal, fragile environments: the Amazon in Boff’s case but also the plains.

Both ecosystems have been colonized and dominated by outside interests, and the dependency of the resulting ecological regimes on outside resources provides perhaps the best measurement of sustainability, both ecologically and economically. I propose that a local ecosystem cannot be sustainable if it is dependent on outside resources to sustain itself or if its own resources are being exploited for the benefit of outside interests. The first case is self-explanatory; the second leads to what has been called the “tragedy of the commons,” which is really a misnomer for the tragedy of the colonial system. While commons have a system to limit access and resource use by their members,³⁸ it is the colonial and neocolonial regimes that open resources to exploitation by outsiders who have no interests in the preservation of the ecosystem but whose only goal

is to exploit and export the resources for profit and thus leave behind a wasteland, often quite literally. It is the control of resources by those alienated from local ecosystems, including the forced creation of open-access regimes, that often, though not always, leads to unsustainability. It is not an accident of history that the most unsustainable use of resources is occurring in the most globalized era: the current use of resources is still built on the premise that some areas of the world can sustain themselves with resources imported from others in a so-called free market—a system that is based on negative reciprocity on a grand scale.³⁹ The alienation from social and ecological relations that enables ecological and economic negative reciprocity expresses itself in dependencies that are an indicator of unsustainable ecosystems.

From at least Clovis times, the plains ecosystem has been integrated into a trade network with other ecosystems. Through the following millennia, trade activities fluctuated, but the plains became integrated into a substantial continental trade network during the Early Woodland period (3,000 B.P.).⁴⁰ Control over this trade rested largely in local hands, even when the system became enlarged to incorporate Europe. One could argue that during the early fur trade Paris was as much an outpost of the plains trading system as the Mandan-Hidatsa villages were of the European trade. This changed gradually as trade went from the exchange of exotic and largely symbolic goods to the trade of foreign technologies and materials that affected the survival of indigenous groups. To Europeans, the fashion of beaver pelts could be replaced by another trend; after a few generations, indigenous people had become dependent on material goods they did not themselves produce. With the near extinction of the buffalo, plains people became dependent on imported fundamentals such as food and clothing. The slaughter of the bison also marks the beginning of ecosystems on the plains that are forced onto the region, a development that eventually brought industrialized and postindustrial agriculture to the region. Agriculture, initially expanded across the plains to create Jeffersonian, self-sustainable yeoman farmers, has created perhaps the most dependent landscape.

It is obvious that mineral, coal, gas, and oil extraction from the plains is not sustainable in the long term. Agriculture, which is still connected to romantic ideas of farmers as the democratic, hard-working backbone and the plains as the breadbasket and heartland of the country,⁴¹ often seems by its nature sustainable. However, industrial agriculture can be as alienated from the land and as dependent on and controlled by the outside as other manufacturing industries. Neoliberal ideologies turned communities and farms into “goods that could be bought or discarded, constituted by individuals who had no common plight other than their economic worth.”⁴² The fur trade exported resources until they were gone. Bison hunting, cattle ranching, mining, and farming followed suit. All of these ecological regimes, once managed industrially, exploited

supposedly free resources—animals, minerals, soil nutrients, grass, people—to turn enormous profits. In turn, these resources were used to and gave impetus to colonize other ecosystems. Bison leather served the British army and the growing industrialization until synthetic products replaced it. From the moment that farmers and politicians recognized the need for fertilizer in order to maintain their agroecosystem, guano became another essential mineral to be mined and shipped from territories that now were annexed as vital to the national interest. As early as the 1850s, Henry Carey warned that globalized agriculture was responsible for soil nutrient losses and a growing agricultural crisis.⁴³ Since then, a “growing demand for modern agricultural inputs allowed American corporations to expand and integrate their markets by linking national and regional markets and by vertical integration . . . developing an agro-industrial complex.”⁴⁴ On the plains, this complex is in need not only of nitrates and fossil fuels but also of water. Although newer research has focused on finding dry-farming methods for better sustainability,⁴⁵ the depletion of the plains aquifers remains a great concern for the future resilience of the plains ecosystem.⁴⁶

The solution to unsustainable ecosystems is theoretically simple: when the problem is recognized—that costs are higher than profits—resource uses must be changed to bring them back within the range of sustainability. This is the rational choice that, theoretically, anybody would make. In practice, however, ideological resilience, that is, the ability to defer these costs to the unspecified although sometimes very near future or to the unspecified although well-known other often leads societies to ignore the problem until the system collapses. On the plains, costs have been displaced to Native peoples (by stealing the land and resources), to the anonymous ecosystem (by overusing the resources), and to the farmers (by keeping them in a debt cycle). These deferrals are, of course, denied under the mantra of free choice. Wilson and Tyrchniewicz, for example, see the “potential for an unsustainable system” if “the market fails to establish value in terms of price, i.e. market failure.”⁴⁷ It is the failure, then, of those who are exploited and colonized to not set a price on their resources; alternatively, it is the failure of the market, which of course makes profits exactly because of this presumed failure. Because the discourse of the free market and rational choice has become so hegemonic and is associated with romantic ideas of farmer self-sufficiency, it is hard for those within the ecosystem to argue against exploitation. In her fieldwork with Canadian farmers, Birgit Müller found that, because “the dominant worldview of the prairies is so firmly committed to the value of hard work and the belief in progress, it became almost impossible for them to rethink their situation and envision alternatives.”⁴⁸ Shaking the cycle of dependency on debts, equipment, hybrid seeds, fuels, fertilizer, and, not least, food is incredibly difficult because many farmers see the resulting lifestyle changes as an admission that their previous methods have ended in failure.⁴⁹

The dependency of the plains is a common one in the early twenty-first century, and the unsustainable exploitation of the plains' ecosystem resembles very closely that of other regions, especially what used to be called the Third World and is now sometimes called the Global South.⁵⁰ Farming, even as a business, is more and more directly tied into dependencies. About a third of all commodities grown in the United States are raised under contract to increase the "ability of processors to monitor production or control production inputs."⁵¹ Perhaps the largest irony of all is that in the so-called breadbasket of the plains, more and more people live without access to edible food and experience hunger: farming has become so industrialized that farmers can no longer eat what they grow. The most rural counties, especially on the plains, have become so-called food deserts. At this juncture, the meaning of value-added agriculture becomes a cruel joke. It might be surprising, or perhaps not, that, for example, a UN Sustainable Development Innovation Brief in 2007 continued to promote the supposed opportunities of "high value-added agricultural products" for sub-Saharan Africa. Instead of growing food for their domestic markets, the report suggests, developing countries should take advantage of "the rise in imports of agricultural products by developed countries [that] has constituted an opportunity to upgrade and diversify their agriculture and agro-industry, which in turn has stimulated growth."⁵² It is exactly the demand for growth that turns "sustainable development" into an oxymoron.⁵³ Unsustainability is at its core the belief that, somehow, the limited resources of one planet can sustain the limitless growth of a capitalist free marketplace. Growth is the problem: admitting this, however, would necessitate a change in economic ideology, worldview, and lifestyle that will be hard to enforce. Within a few decades, perhaps, some of the resources that support the current ecological regimes will be tapped out: water and oil and, next, coal and gas. There is no doubt that this will bring along yet another crisis in plains history. Everything seems to suggest that the plains ecosystem will be resilient enough to rebound, perhaps in different form but viable, nonetheless. Current research on different forms of agriculture adapted to dry conditions and climate change coming to the plains⁵⁴ might then be put into practice.

The ecological historian Donald Worster wrote that, in his view, "the most compelling lesson we can learn from the history of the Great Plains is that the best adaptation to climate can never be achieved merely by private-property institutions or entrepreneurial thinking."⁵⁵ Market economics have to be ignored, he argues, to implement successful ecological restoration programs. Similarly, Aldo Leopold argued in 1924 that, "to protect the public interest, ultimately the use of all resources will have to be put under public regulation, regardless of ownership."⁵⁶ No public regulation is, of course, useful if regulators are not doing their job and instead are acting as caretakers for resource-exploitation

industries, including agriculture. The problem is not private or public property but the culturally constructed need for indefinite growth. Thus, Buckland is right when he writes that there is a need “to place farmers at the centre of decision-making regarding the evolution of farm institutions and new farm technologies.”⁵⁷ However, as the plains model clearly shows, farmers, ranchers, hunter-gatherers, and horticulturalists who are dependent on outside interests will not be in a position to make decisions conducive to the sustainability of the local and therefore global ecosystem. Outside interests will not be concerned with making those decisions as long as they are making profits from the supposedly free or extremely cheap resources upon which they depend.

The plains can offer some lessons on sustainability. Like the ecosystem from which they derive, they are deceptively simple: limited resources do not allow the pursuit of unlimited goals; the imposition of global ideologies on local realities may result in the colonial exploitation of resources (and that is often the goal); resources are never free, although they are often taken as such; economic decisions taken in a situation of dependency cannot work for the good of local resources. The final lesson to be learned from the plains, as from other marginal ecosystems, is this: ecological sustainability cannot be reached under any economic system that necessitates constant growth. The resilience of ecosystems is thus pitted against the resilience of ideological hegemonies, and if anything is to be learned from history it is that humans see only what they want to see. As long as those in control of the political, social, and ecological discourse can afford to overlook the degradation of natural, cultural, and social ecosystems such as the plains, sustainability will remain an empty rhetoric and we have to hope for eventual resilience.

Notes

1. Flores, “A long love affair with an uncommon country,” 10.
2. Ibid.
3. Leopold, “Pioneers and Gullies [1924],” 112.
4. Schroll, Thorn, and Kjaergard, “Resilience is more than an elastic jump,” 1.
5. Krupnik, *Arctic Adaptations*, 237.
6. Worster, *Nature's Economy*, 217.
7. Foreman, *Rewilding North America*, 34–44.
8. Bennett, *Human Ecology as Human Behavior*, 82.
9. See for example Levi-Strauss, *Tristes tropiques*, 93–94: “The “sublime harmony [of beautiful, ordered, intact ecosystems], far from being a spontaneous manifestation of nature, is the result of agreements painstakingly evolved during a long collaboration between man and the landscape.”
10. Roe, *The Indian and the Horse*, 1.
11. Holder, *The Hoe and the Horse on the Plains*, 20.
12. Krupnik, *Arctic Adaptations*, 238–239.
13. See, for example, Nash, *Wilderness and the American Mind*, 23–43.
14. Isenberg, *The Destruction of the Bison*, 93–113.

15. Flores, "Wars over Buffalo."
16. Braun, "Ecological and unecological Indians."
17. Webb, *The Great Plains*, 44.
18. *Ibid.*, 206–207.
19. *Ibid.*, 245.
20. Donahue, *The Western Range Revisited*, 133–143.
21. Russell, *Kill the Cowboy*; Starrs, *Let the Cowboy Ride*.
22. Licht, *Ecology and Economics of the Great Plains*, 67–72.
23. Bennett, *Human Ecology as Human Behavior*, 83, italics in original.
24. Turner, *The Frontier in American History*, 147.
25. Cunfer, *On the Great Plains*, 218.
26. *Ibid.*, 219.
27. Turner, *The Frontier in American History*, 148.
28. Campbell, *Magnificent Failure*, 29; Licht, *Ecology and Economy on the Great Plains*, 13.
29. Bennett, *Human Ecology as Human Behavior*, 261; but see Cunfer, *On the Great Plains*, 24.
30. Licht, *Ecology and Economics of the Great Plains*, 17.
31. *Ibid.*, 53.
32. Cunfer, *On the Great Plains*, 8.
33. Licht, *Ecology and Economics of the Great Plains*, 53.
34. See, for example, Samson and Knopf, *Prairie Conservation*.
35. See, for example, Braun, *Buffalo, Inc.*
36. Boff, *Cry of the Earth, Cry of the Poor*, 67.
37. *Ibid.*, 129.
38. Berkes, *Sacred Ecology*, 96.
39. On negative reciprocity, see Sahlins, *Stone Age Economics*, 185–215.
40. Hoffman and Graham, "The Paleo-Indian cultures of the Great Plains"; Baugh and Ericson, *Prehistoric Exchange Systems in North America*.
41. Danbom, "Why Americans value rural life"; Logan, "Rural America as a symbol of American values"; Howarth, "The value of rural life in American culture."
42. Edmondson, *Prairie Town*, 90.
43. Foster, *Marx's Ecology*, 150–153.
44. Buckland, *Ploughing up the Farm*, 99.
45. For example, Padbury et al., "Agroecosystems and land resources of the Northern Great Plains"; Tanaka et al., "Dynamic cropping systems for sustainable crop production in the Northern Great Plains."
46. Sophocleous, "Groundwater recharge and sustainability in the High Plains aquifer in Kansas, USA."
47. Wilson and Tyrchniewicz, *Agriculture and Sustainable Development*, 32.
48. Müller, "Still feeding the world?," 401.
49. Davidson, *Broken Heartland*, 89–100.
50. *Ibid.*, 159.
51. Martinez and Davis, "Farm business practices coordinate production with consumer preferences," 35.
52. Kjällerström, "Agro-based Industries and Growth: Prospects for Sub-Saharan Africa," 1.
53. Braun, *Buffalo Inc.*, 179–180.

54. See, for example, Cutforth et al., "Adaptation of pulse crops to the changing climate of the Northern Great Plains."
55. Worster, *An Unsettled Country*, 118.
56. Leopold, "Pioneers and Gullies [1924]," 113
57. Buckland, *Ploughing up the Farm*, 203.

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Sarah L. Quick

Southern Slow Foods

Ecological Awareness through Gourmet Heritage

This book's call to action to scholars was to consider subsistence patterns against their long-term ecological impacts. Here, I examine how others, in this case, contemporary food producers and entrepreneurs (as well as consumers), also broach such considerations. I investigate the ecological awareness promoted by the operation of a successful mill, Anson Mills, in Columbia, South Carolina. Like the scholars represented in this book, those involved in producing and selling Anson Mills' products ask how past subsistence strategies might inform contemporary strategies to create more sustainable farming practices and nutritionally viable food. This research inquiry stems from an ongoing ethnographic study on local and slow-food movements in South Carolina in which several overlapping concerns unite these advocates: a desire to preserve historical and better-tasting varieties of food, an interest in sustainable and organic farming as well as seasonal and local foods, and a concern over the lack of biodiversity in late capitalism's food-production system. Although the history I examine is very recent, the history that Anson Mills engages with is not so recent. This analysis aligns with historical ecology's interdisciplinary approach and its practice of attending to culture as it relates to ecological matters (Crumley 1994).

COLUMBIA'S LOCAL FOODIES

This research inquiry began with and here still largely focuses on Anson Mills, which sells high-end organic, "heirloom"¹ grains locally and globally. Nevertheless, Anson Mills' existence and success are tied to other locals as well as to global food movements. Rosewood Market and Deli, which opened in the early 1980s (Ligon 2005), is the oldest Columbia business that promotes a local counterfood culture. Although Rosewood engages health-related food awareness beyond the local and slow-food movements, it remains a major hub for those involved in the local and slow-food movements (as entrepreneurs and consumers), even as it has had to compete with larger grocer-retailers promoting

overlapping food niches, with Earth Fare opening in Columbia in the late 1990s and more recently Whole Foods's appearance in the fall of 2012.

In the late 1990s Anson Mills and the Caw Caw Creek pork farm started, both promoting slow-food values in their high-end products. Their respective creators, Glenn Roberts and Emile DeFelice, also sometimes collaborate: Anson Mills has donated some of the by-products of its milling process to Caw Caw Creek for pigfeed, and Caw Caw Creek has offered Anson Mills products at its table at a local farmers' market, also managed by Caw Caw Creek. Both Roberts and DeFelice have also been active in Slow Food USA, modeled on the International Slow Food movement begun in Italy (see Leitch 2008; also Petrini 2003, 2007, 2010) and most famously taken up in the United States by West Coast chef Alice Waters. In addition, their presence in promoting and representing Southern food to the larger gourmet food world is substantial. Some recent examples are a blog post about a visit to Anson Mills by New York chef Tom Colicchio of *Top Chef* fame that appeared on the website FoodandWine.com (Colicchio 2009) and a *New York Times* article, "Southern Farmers Vanquish the Clichés" (Moskin 2011).

Local Columbia consumer advocates have also become more active through organizations and local food events. Slow Food Columbia, the local chapter of Slow Food USA, formed in 2008 and meets every one to two months. Lately members have met at City Roots, a sustainable urban farm that opened in 2009 and that is another hub in the local food network. City Roots sells seasonal fruit and vegetables on site, at farmers' markets, and to local restaurants such as Rosewood Deli as well as to more upscale restaurants, some of which have also featured Anson Mills and Caw Caw Creek products. This urban farm joins many other smaller-scale farmers in the region who have become active in selling their products at farmers markets as well as to Rosewood Market and local restaurants.

The bulk of my analysis here concerns Anson Mills, a locally operating mill that continues to thrive because of its global connections. Nevertheless, Anson Mills' vision is informed by a historically conscious critique of agribusiness. My analysis stems from interview-conversations with Glenn Roberts, Anson Mills' creator, in 2009 and with Ben DuBard,² who worked as a miller and a seedsman (more on this term later) for Anson Mills, in 2010. In addition, conversations with others contracted by Anson Mills as well as Internet media supplement this analysis.

ANSON MILLS AND THE CAROLINA RICE KITCHEN

When I talked to and later met Glenn Roberts at Anson Mills in the fall of 2009, he very willingly discussed Anson Mill's start, the history and gamut of grains

farmed by him and by others with whom he contracts, his goals for and ideas about sustainable farming broadly and rice farming in particular, as well as Anson Mills' marketing successes and failures. Besides Anson Mills, Roberts also often referred to the efforts of the Carolina Gold Rice Foundation, of which Roberts is president. The Carolina Gold Rice Foundation is a conglomeration of farmers and other folks interested in reviving rice farming and cuisine in the Carolinas (Carolina Gold Rice Foundation 2010).

Reviving Carolina Gold Rice has been Roberts's core passion. Although Anson Mills started in 1998 with and is still famous for its grits, Glenn Roberts's rationale for what he eventually pegged as Anson Mills—the name alludes to a street in Charleston, South Carolina, and not in Columbia, where the mill is located—was Carolina Gold Rice. He recounted Anson Mills' origins in the context of his own life story, describing an event tied to his previous occupation as a historical preservationist-architect-developer reconstructing buildings in the Old South. For openings at renovated buildings, he often featured Southern cuisine, and at one event he arranged for an authentic dining experience with Carolina Gold Rice on the menu. He was not satisfied with the rice he was able to acquire.

Now more than 25 years in the past, this experience piqued his interest in growing the rice himself, and he started his quest to make Carolina Gold Rice again relevant in America's cuisine. He (and others)³ researched the coastal farming techniques of the Carolinas and Georgia in the pre-Civil War era and in the earlier colonial period. Besides learning about the other foods and crops that coexisted with historical rice fields, many of which were used in crop rotation, he also began to realize how difficult it would be to reconstruct such farming practices. The expense of getting enough land and altering it for tidal and trunk agriculture alone limited his initial prospects in rice farming.

Instead, he went with producing maize and grits as products to market. What were available on the market for grits were nice looking and texturally appealing but nothing like the flavorful grits that he had heard his mother and other elders speak of. His mother referred to "kitchen corn" as the subsistence-farmed corn they used in home cooking, corn that had not been grown as a cash crop. Interestingly, bad grits (instead of the bad rice mentioned earlier) and his mother's expertise and dissatisfaction with contemporary offerings of Southern-heritage food provides an additional Anson Mills origins story on the company's website (Anson Mills 2015c). Nevertheless, Roberts searched for the seeds and farming techniques that could re-create this flavorful kitchen corn. Ultimately, he sought out farmers who did use corn as a cash crop, albeit an illegal one—he relied on bootleggers who grew and milled corn for moonshine. Once he found these sources, he learned how such farmers irrigated through natural watersheds, maintained seed stocks within their families, and also based

their cuisine on their own subsistence farming. Thus the well-storied commercial origins of Anson Mills began in 1998, when Glenn Roberts took what he had learned and produced his own crop of Carolina Gourdseed White, which he then milled using historical milling techniques (Anson Mills 2015c; see *Al Forno* 2008 for similar versions of Anson Mills beginnings).

Roberts describes his initial forays into farming and milling as a process in which he learned through trial and error, a reliance on other farmers' knowledge and experience, and historical research and collaboration with historical experts. By 2000 Anson Mills was milling ten different corn dent varieties and was selling these as grits to chefs in Georgia, the Carolinas, and other select chefs around the country (Anson Mills 2015c). And with this success, rice could come back into the picture. In 2001 the company was able to produce "certified organic Carolina Gold rice" as well as "Thirteen Colony" or "Red May" wheat (Anson Mills 2015c; see *Slow Food USA* 2010 for slightly different dates and account). More recently Anson Mills has added "organic Carolina Gold rice fields in Georgia, North and South Carolina and Texas" and 30 acres of South Carolina rice fields located on the Edisto River at the site of some of America's oldest "tidal trunk and dyke rice fields" (*Slow Food USA* 2015).

What Anson Mills produces has expanded, in part, because of the research into the crops used historically in rice field rotation but also in response to requests from chefs. The variety in Anson Mills' current list of wholesale products available to chefs is staggering. Besides several corn varieties milled for various levels of coarseness for grits, cornmeal, corn flour, and polenta, Anson Mills offers Carolina Gold rice and other rice varieties and rice flour, wheat-based flours, Italian farro, rye and oats, a couple of varieties of Sea Island peas and flour, Benne seed and flour, and even Japanese buckwheat and sobakoh (Anson Mills 2015a).

Figure 1 presents the major nodes related to the production and distribution of Anson Mills' grains for sale, its research, and what Roberts calls "seed repatriation" links, as well as other organizational links. On the commercial production side, Anson Mills contracts with organic farmers along the East Coast and Texas who are willing to grow grains (and some legumes) with lower yields than is the norm in agribusiness. Besides having to be certified organic by the U.S. Department of Agriculture, these farmers use the older landrace varieties (often in rotation) as a more sustainable farming model. Grains are then processed at the mill according to chefs' orders. As DuBard explained, "everything [is] to order; they don't mill . . . in advance." Since the mill uses various ways of processing the grains depending on the grain and its future uses, it requires specialized knowledge and skills from what Anson Mills calls its artisanal millers.

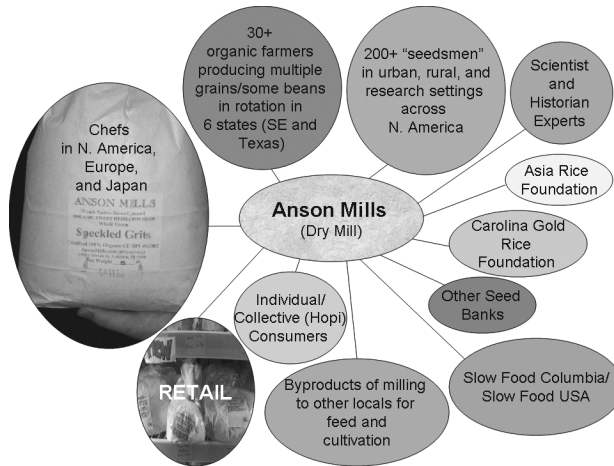


FIGURE 1. *Anson Mills network.*

Most Anson Mills sales are wholesale and direct to chefs. Nevertheless, a few retailers offer their products, and individual consumers may purchase them through the Anson Mills website although at higher expense and with fewer choices than are available to chefs buying in bulk. Roberts characterized the retail end of Anson Mills as minimal (less than 1 percent of total sales),⁴ and while Anson Mills has cultivated local relationships such as that with Rosewood Market, without the regional, national, and even international connections to chefs Anson Mills would not survive.

Anson Mills is also a channel for Roberts's mission to save seeds that are out of circuit because of modern agribusiness practices. Anson Mills' revenue feeds back into research and preservation of seeds beyond those produced for market sales, what Roberts calls "seed repatriation." As he explains it, Anson Mills receives revenue primarily through sales to chefs in the United States and beyond; this keeps the production farmers and the mill aloft but is also then pumped into funding smaller-scale farmers or "seedsmen" who preserve and research seed stocks unavailable in the market. As Ben DuBard describes it, "Glenn is probably preserving in that warehouse maybe 50 varieties of corn right off the bat, and that doesn't even count the stuff that he maybe is having other people take care of in other places." These "seedsmen" (or "seedswomen" in many cases) along and beyond the East Coast are contracted to keep the seeds maintained and available, although a few seed stocks may eventually be used for grains or other foods produced and sold on the market.

At this stage, Anson Mills contracts with many more seedsmen than organic farmers for production (roughly nine times as many, according to the figures provided in my November 2009 conversation with Glenn Roberts): some grow their seeds in urban settings, some in rural, and some are affiliated with research institutions. Those seedsmen contracted by Anson Mills that I personally know plant very small plots (less than an acre) in order to maintain and potentially produce more seed varieties. Roberts summarizes this larger mission and shift toward seed repatriation with the following description: when Anson Mills started, 90 percent of revenue would go toward production and 10 percent toward seed research; currently, 90 percent goes toward seed research and 10 percent toward production, although production has also risen by 90 percent from the earliest period. In addition, Anson Mills has provided ground organic corn to the Hopi Nation at below wholesale prices because drought conditions and coal company interference have affected their corn crop waterways.⁵

Roberts is emphatic that Anson Mills does more than revive and produce ancient grains in order to sell to chefs. In our conversation, he periodically reverted to Carolina culinary practices as they revolved around rice farming—the interrelationship of food, farming, and the culture surrounding this cuisine. Although grits are still a mainstay of Anson Mills’ sales, the continued research involved in reviving not only the accompanying rotation crops (of which corn was one) for rice fields but also the food cuisine, the “Carolina Rice Kitchen” (Hess 1992), continue to drive him. He speaks frankly about this cuisine’s overwhelming absence in most American’s understanding of Southern-heritage foods. For example, reviving rice bread in the Carolinas has been a long-term goal; yet, even with all of Anson Mills’ success and growing fame as well as two rice bread symposiums sponsored by the Carolina Gold Rice Foundation, this artisanal bread has not come back as a regular item in a restaurant or retail setting (see Anson Mills 2015b for a recipe for Carolina Gold Rice bread “country style”).

He reflects on all the factors mitigating against such a culinary revival, both consumer and production based. For rice bread in particular, artisan bakers are few and far between in South Carolina; in addition to the expense of growing the rice itself, the rice must be milled and the bread produced in ways counter to modernized, mechanized technology. This problem makes the bread too expensive and its production too inefficient for contemporary bread makers. For rice more broadly, he noted that most consumers (and especially those in the South) expect to buy rice at very cheap prices. Anson Mills’ Carolina Gold Rice does not sell cheaply: at retail value it is nearly seven dollars for fourteen ounces (Anson Mills 2015a). In addition, for those within and outside the South, Southern cuisine often connotes lower class, not gourmet.

While the rice bread dilemma remains frustrating to Roberts, he continues to revisit his original quest of reviving the Carolina Rice Kitchen. However,

gaining converts on the benefits of these foods and farming techniques seems to work only through iconic foods, through those foods that already have symbolic capital. Seed research and the complex crop rotation that accompanies a sustainable version of rice farming often land on deaf ears, but food does not. This approach is easily seen on the Anson Mills website and in other media attention to Anson Mills' culinary and recipe appeal. Anson Mills has achieved considerable national media attention when it comes to food.

Before Anson Mills was even a named entity, Glenn Roberts's quest was about reviving the food heritage of the Old South. If he had been able to purchase what he deemed suitable products for Southern-heritage dining experiences, perhaps this quest would not have begun. At least initially, this mission was not one with an outright ideological emphasis on moving agribusiness toward more sustainable farming practices or alternative approaches to "running a business" ("business" is a word that he refuses to use in describing Anson Mills). However, as he has learned about the historical farming practices in the Carolinas and Georgia—how global and multicultural these foodways and farming technologies were and yet how different the technological and socioeconomic approaches to producing these foods were—his goals shifted to a critical awareness in ecological matters. His approach became one that runs counter to the recent industrialism in farming, milling, and food manufacture more generally.

As he explains about the farming he is trying to reconstruct, the farming that coincides with the "Carolina Rice Kitchen," this technology and this economy run counter to the industrial agriculture and the cash crops that now form the bulk of our contemporary food choices. The old ways were discarded in favor of efficiency and high yields in production as well as ease in shipping. His attention to historical farming and culinary practices necessitates a reconstruction or rather a reinvention of the culinary concerns and subsistence practices of a past era. Reinvention should be emphasized since obviously Anson Mills is unable to reproduce the plantation model of managing slaves as a labor force.⁶ This ecological and culinary awareness also expanded his mission, resulting in connections to organic farming, the Slow Food movement, and, more recently, the Asia Rice Foundation, because of its food security goals.⁷

Like the originators of the Slow Food movement in Italy, in the United States Roberts developed an interest in reviving Southern culinary traditions that bridges concerns "with the defense of local cultural heritage, regional landscapes and idiosyncratic material cultures of productions . . . [and] international biodiversity and cosmopolitanism" (Leitch 2008: 393). Paralleling this global/local dynamic in describing how he developed a revenue-producing operation, Roberts points to how he contracts with farmers regionally, not just locally, in part to ensure that there are no crop wipeouts due to natural disasters. Nor does

he consider the farming and culinary practices he is attempting to reconstruct local; he sees them as regional and partially couched within a global market. Furthermore, some of his contracts with seedsmen are local but some extend beyond the Southeast. Finally, sales are definitely not locally based: only through a global market in which many of the revenue sources lie outside South Carolina does Anson Mills garner enough sales to keep afloat. As scholars studying the Slow Food movement suggest, producers of local and artisan food varieties cannot survive on local sales alone but must rely on esteemed “distant consumers,” especially when the local place does not carry the cachet of culinary place icons like Italy (Fonte 2006; Friedmann and McNair 2008).

FROM TABLE TO FIELD

Quoting and reversing our conference title, it is from the table to the field that Glenn Roberts and others involved in these interrelated food movements engage with and imagine culinary histories. In this case, it is the Carolina Rice Kitchen and the foodways of the rice plantation days that inform Anson Mills’ farming and milling. Nevertheless, I have come to think of Glenn Roberts as a *bricoleur* in his pastiche of knowledge sources—contemporary culinary experts, historical and contemporary subsistence farmers, food historians, archaeologists, biology experts, and geneticists—that inform decisions related to farming, milling, and seed-saving. Ben DuBard describes this knowledge base as having three components; it involves (1) knowledge of techniques for farming diverse grains; (2) knowledge of processing methods for certain grains in a certain manner for certain purposes, that is, the variety of milling processes required depending on the grain variety and food uses; and (3) knowledge required in the final food preparation according to a home or local cuisine.

I already spoke to the global-local spatial dynamics that Anson Mills engages, but in terms of temporal scale, Anson Mills is also provocative. Anson Mills invokes a specific past in the rice plantation era as well as much broader periods in terms of colonial and precolonial use of corn and other grains. Obviously, the labor practices from these earlier periods cannot be reconstructed and are reinvented alongside their food production models. While Anson Mills is tied into a global market, the kind of farming it supports is one that its proponents see as a way to revive subsistence-based models so that farmers may eventually be well equipped to deal with global food disasters and become more independent. Therefore, current and future food concerns also inform the Anson Mills mission; in particular, maintaining biodiversity and food security for the future requires the seed repatriation mission through the sponsorship of seedsmen. DuBard, who relates his own food and farming ideology to a permaculture philosophy (see Vettero and Lockyer 2008), sees reviving this kind of

knowledge as a step toward surviving within more local-based food and energy economies. He sees Anson Mills' approach as an effective strategy for gaining the capital to fund such knowledge.

Anson Mills is refashioning contemporary agricultural practices and food economies toward ones that it sees as historically informed, based on local varieties, and more sustainable. Whether or not the sustainability of the Anson Mills approach will live up to the culinary ideals sought through the Carolina Rice Kitchen remains to be seen. Regardless, the consequences of ignoring this culinary heritage and local ecology are ever-present concerns for both Roberts and DuBard. Perhaps we might think of the Anson Mills approach as a sort of pragmatist historical ecology.

Notes

1. As Glenn Roberts, Anson Mills' creator, told me, "heirloom" is the term Anson Mills uses for convenience and public recognition. However, he prefers the term "landrace," which he used throughout our conversation to refer to the grains that he is salvaging and preserving. He realizes that most people do not know the term "landrace," and I had to ask him what he meant by it since it was previously outside my vocabulary. Since our conversation, Anson Mills has updated its website, providing a glossary of terms like "seedsman" and "landrace" crops. Seedsman is defined as "a person who works with landrace crops, collecting seeds from the current crop and selecting those with traits thought to promise success for future plantings" (Anson Mills 2012a).

2. DuBard's links within Columbia's local food network are also dense: he worked at Rosewood Market for ten years, farmed a local Community Supported Agriculture from 2005 to 2009, and helped the City Roots farm get up and running, while also returning to Anson Mills as a part-time miller. He also helped to start and remains active in Slow Food Columbia.

3. Richard Schulze (2005) first tracked down the Carolina Gold Rice seeds in a USDA seed bank and then planted the first successful crops in more than 50 years, in the late 1980s. Others involved in the recent research and farming of Carolina Gold Rice are found on the Carolina Gold Rice Foundation's website; besides Anson Mills, Carolina Rice Plantation (Carolina Rice Plantation 2005) produces Carolina Gold Rice for sale.

4. In Columbia, only three sites regularly offer Anson Mills products: Rosewood Market, the Soda City farmers market, and, recently, the Gourmet Shop. According to an online query, a cheese shop in Brooklyn has recently offered Anson Mills products (Chowhound Discussion 2012).

5. I heard this informally and found an online reference through a Facebook site created to help the Hopi raise money to pay for the cost of this corn. More recently, Anson Mills has mentioned this connection on its website (see Anson Mills 2012b).

6. Roberts readily acknowledges the legacy of African and Gullah farming and culinary knowledge as well as the continued hold "race" has had on Anson Mills' ability to make connections to the Gullah community.

7. Roberts is currently a board member of the Biodiversity Committee within Slow Food USA, along with the Caw Caw Creek pig farm owner Emile DeFelice (Slow Food USA 2009). Roberts explains that the rationale for being affiliated with the Asia Rice Foundation was that the Slow Food organization does not fully address food security problems.

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A Good Place

Aesthetic Pleasure and Landscape Resilience

Fundamentally, landscapes are a creative act. The action of visualizing a place and actualizing it by planting, earth moving, and manipulating the landscape with roads and other shifts is a process of taking the abstract vision of a “good place” and rendering it material. This creation of landscapes undoubtedly has political and economic ramifications, and economic concerns can do battle with aesthetic preference; however, at its root, it is an act of creation. As an act of creation, it is an act of esthetic choice. What is considered pleasing in a landscape is a sensual decision as well as a potentially economically rational one. Aesthetics are multiscalar phenomena; for example, what is attractive to me, to the community, and to the larger community may all be held to different standards/ideas, though these are interlocked. It is, in this way, a reflection of cultural practice and of the multiscalar qualities of landscape.

Landscapes are the major concern of historical ecology: “The landscape is where people and the environment can be seen as a totality—that is, as a multiscalar, diachronic, and holistic unit of study and analysis” (Balée 2006: 2). Historical ecology includes human activities and agency in landscape processes and insists on the need for a long-term perspective (there are similarities to the annales school of history, with its *long durée*; Braudel 1980; Balée 1998, 2006). Historical ecology also has a concern for sustainability and resilience of human landscape interactions over time (Crumley 1994).

Resilience theory is a notion of the maintenance of social-ecological relationships that allows for change/adaptability and continuity of landscape form (as founded by Hollings and others; see Holling and Gunderson 2002). Resilience theory considers social-ecological systems (landscapes) as flexible learning relationships. The idea of stasis is not present in resilience theory as it might be for concepts of sustainability. The maintenance of structure or form while simultaneously retaining flexibility in structure and action (for example, the

capacity for change) is a paradox present in this notion (Redman and Kinzig 2003). Failure to maintain structure in the face of rapid change can lead to societal “collapse” (Scarborough and Burnside 2010).

This essay provides brief examples from Europe, where aesthetics has had a role in landscape formation and resilience over a period of 100 or more years in ways that may be entwined with economic and political activity. These examples have implications for resilience theory and landscape conservation. The three examples are both historic and modern and demonstrate continuity and change in the implementation of esthetic ideas in landscape, along with economic and political concerns.

EXAMPLES: MEDIEVAL GARDENS, VILLES FLEURIES,
AND PONDS AND MILLS IN BURGUNDY

European medieval gardens are significant because they are one of the first places where planting and creating landscapes specifically for pleasure as a goal is documented in art and in historic documents. They also contain commonly preferred landscape elements as documented by behavioral ecologists, including diversity, shelter, and water features (Kaplan and Kaplan 1989).

Albertus Magnus describes pleasure gardens in a treatise from 1250 (John Harvey’s translation):

“There are, however, some places of no great utility or fruitfulness . . . these are what are called pleasure gardens. They are in fact mainly designed for the delight of the two senses, viz. sight and smell . . . [about the lawn] may be planted every sweet smelling herb such as rue, and sage and basil, and likewise all sorts of flowers, as the violet, the columbine, lily, rose, iris and the like. So that between these herbs and the turf, at the edge of the lawn set square, let there be a higher bench of turf flowering and lovely; and somewhere in the middle provide seats so that men may sit down there to take their repose pleasantly when their senses need refreshment. Upon the lawn, too, against the heat of the sun, trees should be planted or vines trained, so that the lawn may have a delightful and cooling shade, sheltered by their leaves. For from these trees shade is more sought after than fruit, so that not much trouble should be taken to dig about to manure them, for this might cause great damage to the turf. Care should also be taken that the trees are not too close together or too numerous, for cutting off the breeze may do harm to health . . . the trees should not be bitter ones whose shade gives rise to diseases, such as the walnut and some others; but let them be sweet trees, with perfumed flowers and agreeable shade, like grapevines, pears, apples, pomegranates, sweet bay trees, cypresses and such like.”

So here we can see that there is a suite of aesthetic choices that is taking primacy over economic or other concerns (“from these trees shade is more sought after than fruit”). Also, the wide diversity of plant choices is documented.

Pleasure gardens were mainly for the rich, the landed gentry, and the upper members of the Church. These were bounded spaces (as were kitchen gardens), and their secondary purpose was to serve as status symbols; land, time, and labor could be forms of conspicuous consumption. This trend continues in a public form in the example of the *Ville et Villages Fleuris* contest in France.

Pleasure gardens and plantings are still obviously a major focus of communities and individuals when creating a landscape. In modern times, the private pleasure garden is often replaced by municipal gardens and plantings. There is still some continuity in the quality of the gardening and plantings; however, the purpose has shifted from the creation of a strictly pleasant personal space with social capital connotations (that is, only elites had pleasure gardens in the medieval period) to a municipal directive toward improving living conditions for the whole community as well as economic aid in the form of the tourists a beautified landscape may attract. In France, this activity of community flower planting is even the basis of a competition among municipalities.

Since the passage of an Association Act in 1901, the National Council of Cities and Villages in Bloom has been responsible for organizing and promoting the *Ville et Villages Fleuris* project. The board of directors has four people on it, who are members of the public sector, tourist industries, and horticulture industries. Its funding is provided by the Ministry of Tourism, the Ministry of Agriculture and Fisheries, and private industry sources (“*Villes et Villages Fleuris*” 2010).

Since 1950 a contest taken place to further encourage towns, villages, and cities to enhance their environment with floral planting. In recent years the scope of the award has also included walking paths and green spaces, as well as the floral plantings. Twelve thousand communities of various sizes compete (“*Villes et Villages Fleuris*” 2010). The website for the *Ville et Villages Fleuris* committee states: “This contest and the *Ville Fleurie* project has taken hold within local communities (*communes*) as a guarantee of a high quality of life” (“*Villes et Villages Fleurie*” 2010). So, the participation in competitive flower planting is highly valued in the areas that participate, at least according to the organizers.

Given the close involvement of the tourist and horticulture industries, it is clear that while the initial encouragement of the competition and rating system might have come from a desire to support only a beautification project, the effort has economic implications in the form of tourist dollars and spending in the horticultural sector. The system of awards also, by its nature as a multitiered governmental award system, is intensely political. However, in addition to the

political and the economic aspects, ideas of what is beautiful are still important to the enterprise, and the flowers, green spaces, and so on improve the quality of life in the communities that participate.

So these garden plantings exhibit some continuity in form—the diversity of flowers (with many of the same varieties being used), the concern for placement of benches and other landscape features, the presence of ornamental trees, and the formality of flower beds, as well as pleasure taken in the gardens, remain. The general form and, to a certain extent, the function (enjoyment) remain in the landscape. However, the nature of access (public versus private) and some aims (economic versus maintenance of status) are transformed. This transformation of utility with retention of form in the landscape is also found in ponds and mills in Burgundy, France.

I am part of a research team working on landscape history in Burgundy, France, in the commune of Uxeau. Dr. Elizabeth Jones, Dr. Scott Madry, and I are putting together a GIS (Geographic Information System) based on historic maps and supplementing it with historic documents to create a picture of land use starting in the 1780s. We are being assisted in the archives by Dennis McDaniel. Our work is being complemented by research by Professors Carole Crumley and Seth Murray, who are creating an ethnography/oral history about land use in the region.

Our initial focus has been on ponds in the area. These show a remarkable continuity, though in the middle of the twentieth century there was a small reduction in the number of ponds. In recent decades (post-1983), there has been an increase in the number of ponds, often in the same places as historic ponds, as well as continued continuity in the pond's locations (Jones et al. 2009).

The ponds in this region are nearly all made by humans, by damming streams. This means that there is some maintenance required; periodic dredging, maintenance of dams, and restocking with fish are all necessary activities. This can, in modern contexts, be quite expensive (Murray and Crumley 2009). In the past, the government recognized the economic benefits of ponds, and consequently they were steeply taxed. Today, the investments in the ponds do not generate monetary returns, nor are taxes on ponds as high.

While the ponds are located in the same places on the landscape as they were historically, their purposes and economic benefits have been transformed. In the past, ponds were related to mills or were associated with fish stocks and were quite lucrative (Jones et al. 2009). Today, ponds are still stocked with fish, but the fish are there for recreational purposes. One of the assumptions of our research was that the use of ponds was expanded after the severe drought in 2003. This does not seem to be the case. Pond owners report that they are keeping the ponds for recreation and because “they have always been there,” that is, for esthetic reasons and for the maintenance of traditional landscapes (Murray and

Crumley 2009). They also express that sharing fish from the ponds with friends and family is another motivation (Murray and Crumley 2009).

So, in the case of the ponds, what was once a primarily economically driven feature on the landscape is now primarily an esthetic choice. This has implications for historic landscape studies, as many times the assumption is that if the landscape is maintained, the landscape's purpose is as well. That assumption is clearly not always accurate.

CONCLUSION

In the examples in this essay, elements on the landscape have persisted for a long time. However, their meanings, control, and economic values have transformed over time, while their form and presence in the landscape remain. So, in the sense of persistence, resilience, and durability (even sustainability), these landscapes and practices qualify. However, in the aspect of utility, continuity is not present. The ways these landscapes are used and the economic value placed on them are profoundly different from what they were, in spite of their retention of form.

The examples also demonstrate the paradox of resilience theory—the flexibility in function that is present in the system that allows for retention of form. However, the question then arises, What precisely is being preserved in a resilient landscape? What is being preserved in the case of these examples is not a form on a landscape alone but also the capacity for humans to take satisfaction from the landscape, through either economic success or esthetic pleasure. Is the retention of satisfaction in the landscape an adequate proxy for resilience? Given the difficulties and, ultimately, the abstraction that the notion of resilience contains, I propose that a measure of resilience, sustainability, or durability in highly inhabited and manipulated landscapes is the satisfaction of the inhabitants. While this quality in a landscape is hard to measure—it cannot be found in maps or in pollen records or even be easily quantified—it may be a more accurate way of thinking about the critical factors in a landscape. A damaged landscape is one in which people are unhappy, and unhappiness may be tangible and preventable by efforts that go beyond merely identifying elements in the landscape that should remain indefinitely and attempting to retain them. Respecting the satisfaction people take from the landscape around them and using it as a measure of landscape quality has the advantage of encompassing environmental concerns and cultural concerns. While people may value overutilization of resources and the accompanying economic gain, ultimately people value green spaces and ecosystems, especially when people can interact with them in a positive way and connect them to their personal, regional, and cultural histories. This focus on community attitude permits flexibility in both

landscape form and function that allows for an approach to landscapes that is dynamic and management that is focused not only on static landscape curation.

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Variable Biodiversity from Managed Ecosystems in Long-Term Chronosequences from the Southeastern United States

Anthropogenic effects on biodiversity are among the largest challenges facing policymakers and environmental managers today. The United Nations Convention on Biological Diversity notes that understanding the effects on biodiversity as either natural phenomena or as anthropogenic events is important for global environmental management, economic development, and elucidating climatic change (Secretariat of the Convention on Biological Diversity 2001; Leadley et al. 2010). The recent assessment of biodiversity estimates by the Convention on Biological Diversity lists coupled human-environmental systems as vulnerable to ecological “tipping points” and, particularly, human induced fire (Leadley et al. 2010). Our ability to mitigate or manage these effects depends on our ability to understand the specific human behaviors and their long-term effects on biodiversity and ecological processes and to predict those effects (Dawson et al. 2011).

Human effects on the environment have been documented for a long time (Kammen et al. 1994; Minnis and Elisens 2000; Stahl 1996). Recent research on grassland plots showed that ecosystems that have undergone decades of fire suppression management are more vulnerable to collapse because of the loss of species diversity (MacDougall et al. 2013). Forests with higher levels of species richness have more biomass, food, and fuel available (Gamfeldt et al. 2013). Consequently, long-term studies of human effects on biodiversity are applicable to understanding past and current cultures, regime change, and resource availability and are crucial to our ability to manage anthropogenic change.

Since biodiversity is a long-term process (Willis and Birks 2006), we need to assess the effects of humans on biodiversity over long time scales with data from historical sciences such as archaeology, geography, and geology. This essay describes a study of 25 chronosequences that span three major physiographic regions and that represent human occupation areas that were settled from as

few as 35 years to as long as 2,000 years. The chronosequences represent varying degrees of succession of forest tree species from zero years to 1,800 years.

Chronosequences are one of the most frequently used methods in ecology to study succession over time (Foster and Tilman 2000). Chronosequences are plots of land that are used to simulate the different stages of succession. Each plot of land is designed to be at varying but known ages of succession. The growth changes can be seriated to identify changes over time (Walker and del Moral 2003). The use of chronosequences can have problems, however. The use of chronosequences assumes that there are no major disturbances to the ecosystem and that all plots have received equal environmental conditions (Willis and Birks 2006; Willis et al. 2005). Even given the problems of using a chronosequence approach, it is useful for inferring basic patterns of succession (Foster and Tilman 2000).

Using archaeological and historical data, this essay describes research that identifies areas of known human activity to define use area catchments within a temperate forest. Those catchments were used to identify areas of the forest to measure biodiversity of tree species. Tree species in the ancient forest were identified with the use of witness trees. Witness-tree studies use historical maps and forest surveys that were conducted by the United States government during the early nineteenth century in the study regions. The data source and relevant biases are described in detail elsewhere (Foster et al. 2004). Chronosequences of witness trees are used in this study as a systematic, representative sample of the forest composition at the time when Native Americans were occupying the study area.

STUDY AREA

The study region (Figure 1) is in west-central Georgia and east-central Alabama in the southeastern United States (N 33° 30' and W 86° 30'). The climate in the study region is almost subtropical, with temperatures ranging from an average of 10° C in the winter to 32° C in the summer. Average precipitation is about 137 cm. The average growing season is approximately 250 days, with November 13 being the average first day of frost and March 8 being the average last day of frost (Burgess et al. 1960).

The region encompasses 1,600,000 hectares of multiple physiographic regions, including the Coosa Valley section of the Ridge and Valley physiographic province, the Ashland and Opelika Plateaus of the Piedmont, and the Fall Line Hills, Black Belt (Black Prairie), and Red Hills sections of the Coastal Plain (Fenneman 1938). The northernmost of these provinces is the Ridge and Valley. Elevations in the Ridge and Valley range from 100 m on the valley floors to 540 m on the ridges. The Piedmont has a wider range in elevations (40–360 m).

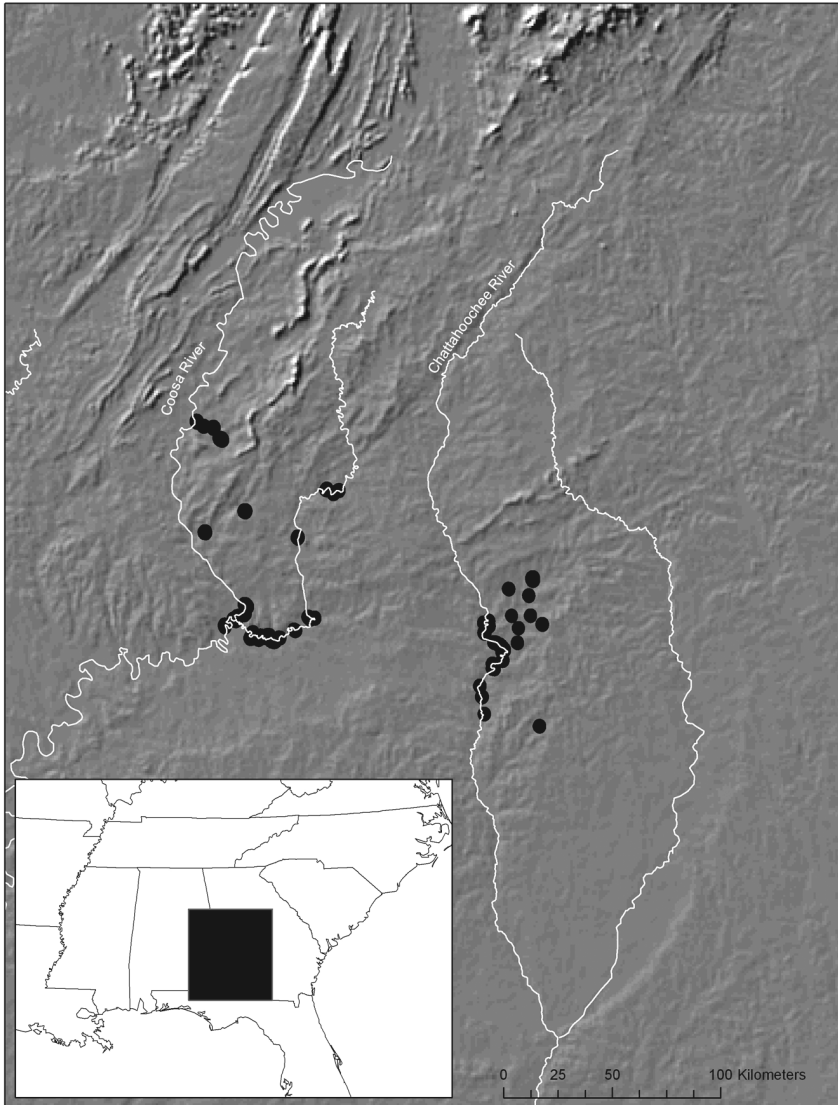


FIGURE 1: *Study area in central Georgia and Alabama, United States, and the location of the human settlement catchments used.*

The Coastal Plain, located in the southern part of the study area, is sandy and relatively flat (Fenneman 1938). Topography is diverse, ranging from highly dissected and rough to broadly rolling. Three major river drainages dissect the area and flow from north to south (Figure 1).

Native Americans have lived in the study area for at least 10,000 years, though the intensity of that occupation and the effect of their activities on the biodiversity of the forest have varied. The earliest human occupation in the study area was by hunter-gatherers during the Archaic Period and was seasonal (Anderson et al. 2007). There were earlier human inhabitants, but those earlier settlements were not used in this study. Human density at settlements was likely about 25 individuals per settlement (Anderson et al. 2007). The earliest sites in this study were from the late Archaic Period (2500 B.C.), when domestication was first developing. After these native people began cultivating foods (Woodland Period, 1000 B.C.–A.D. 800), human settlements were occupied longer during the year and supported higher population densities. Settlement populations varied between about 25 individuals and about 100. The native people were swidden horticulturalists of locally domesticated crops such as sunflower and squash. When maize became a staple food source, around A.D. 1000, population density and agricultural techniques began to intensify. This period was characterized by larger settlements situated near river bottoms. Settlements contained approximately 100 to 500 inhabitants on average.

Human settlement varied along with the subsistence strategies through time in the study area. Subsistence strategies that had an effect on biodiversity are well documented (Foster et al. 2004; Foster and Cohen 2007; Fritz 2000; Hammett 2000). Human use of fire probably had the largest effect on biodiversity. Native Americans have used fire for thousands of years for hunting, for preparing horticultural fields for planting, and for pest management. Fires were used to clear gardens for cultivation multiple times a year. The forests were also set on fire to drive deer in deer hunts on an annual basis. These fires have an impact on the composition of the forest by increasing fire-tolerant species such as pine and early succession species. During the Historic period, the subsistence strategy was very similar to that of the Mississippian Period, but European-Asian crops as well as some domesticated animals such as chickens and pigs were added to the subsistence strategy (Foster 2007).

METHODS

Fifty-six habitation areas were chosen from a population of known archaeological sites that represent human habitation sites spanning 4,830 years of occupation over 16,000 km² in the study area. Sites were chosen on the basis of our ability to collect accurate occupation and population density data for those sites. Sites were limited to those that had evidence of horticulture as a subsistence strategy and that had a wide range of occupation durations. Archaeological sites were identified by the existence of systematic surveys across the landscape and by corroborating location data with historical maps and

government documents. Most systematic surveys included surface inspection and digging standardized test units at 30-meter intervals into the soil until artifacts were recovered and then at 10-meter intervals to delineate the boundaries (Elliott et al. 1995). These sites were recorded in research reports, in state site file repositories in Alabama and Georgia, and on a geographic information system (GIS) using ArcGIS 9.3. Catchments of 3,000 meters of use area were defined around human settlement using a GIS, because 3,000-meter from the study area catchment has been found to represent the extent of Native Americans' measurable effect on the composition of the forest (Foster et al. 2004). Since many of the 56 habitation areas were within 3,000 meters of another habitation, those community catchments were combined into 25 total catchments of human occupation area (Figure 1). Population estimates were obtained from census records when possible and estimated on the basis of the type of archaeological site if no census record was available. Census records were available for 18 out of 25 sites (Swanton 1922). Duration of occupation was measured individually for each settlement through historical references, analysis of time sensitive artifacts such as pottery styles and trade goods, and radiocarbon dating.

Forest composition was measured through the analysis of witness-tree data from historic land survey documents. Witness trees ($n = 52,581$) were digitized from land survey maps covering the entire study area (16,000 km²) into a GIS using ArcGIS 9.3. Detailed methods on data extraction from the witness-tree records are published elsewhere (Black et al. 2002).

After witness trees from the maps were digitized into the GIS, the 3,000-km settlement catchments were used to identify forest study areas. Table 1 shows the variables measured. Biodiversity measures were calculated for each catchment, including number of species and the Shannon-Wiener metric (Peet 1974). The Shannon-Wiener index, sometimes called the Shannon-Weaver index, is a measure of taxonomic diversity calculated from the proportion of the species in the total sample. A low number reflects low biodiversity. The number of species is the sum of the different species in each catchment. Population is an estimate of the human population that lived in each catchment each year while it was occupied. Succession is a measure of the number of years elapsed between the abandonment of the site and the creation of the land survey maps for the catchment area. Succession is zero if the site was abandoned immediately before the land surveys were conducted and increases the further back in time that the site was abandoned. Statistical analysis was performed using SPSS (SPSS 2007).

RESULTS AND DISCUSSION

Twenty-five catchments of human occupation were identified and analyzed. Their loci are mapped on Figure 1. Tree species were counted and summarized

TABLE 1: Table of Catchments Used in Analysis Along with the Variables Collected for Each Study Sample

Shannon- Wiener	Sample Size	N Species	Site Type	Population	Date Range	Occupied	Succession	# towns	Reference
Apalachicola	1.762	197	20	Town	1000	1400–1800	400	27	4 (Foster, 2007)
Atasi	2.420	121	19	Town	300	1600–1830	230	0	1 (Knight, 1985)
Carmouche	1.003	175	11	Village	50	200BC– 1000AD	1200	800	1 (McCullough, 1983)
Coosada Hickory Ground	2.280	150	22	Town	300	1200–1830	630	0	7 (Foster, 2003, Wright, 2003)
Coosa Abicoochee	1.723	281	18	Town	500	1600–1830	230	0	3 (Foster, 2003, Wright, 2003)
Cussetuh Coweruh	1.893	391	26	Town	1000	1200–1830	630	0	4 (Blitz and Lorenz, 2006, Schnell, 1984, Foster, 2007)
Hirchitee	1.846	152	17	Town	300	1715–1830	115	0	1 (Foster, 2007)
Muklsassa Hoithlewaulee	2.375	159	19	Town	500	1400–1814	414	16	11 (Knight and Mistovich, 1984, Waselkov, 1981)
Natchez	1.654	132	11	Village	100	1755–1823	68	7	1 (Foster, 2003, Swanton, 1922, Mereness, 1961)

Nuyaka	2.056	257	23	Town	100	1777–1813	36	0	3	(Foster, 2003)
Ochille Creek	0.717	152	13	Village	15	1790–1825	35	0	1	(Cowie et al., 2001)
Oconee Sauwoogaloochee	1.233	262	18	Town	200	1715–1830	115	0	2	(Swanton, 1922, Hurt, 1975)
Okfuskee	2.030	122	16	Town	500	1700–1830	130	0	1	(Piker, 2004)
Point Towns Yuchi	1.686	405	23	Town	500	1715–1830	115	0	4	(Foster, 2003, Schnell, 1982)
Pukantallahassee	1.619	102	15	Town	200	1720–1832	112	0	1	(Swanton, 1922, Foster, 2003)
Roods Landing	1.375	138	17	Town	1000	1100–1600	500	225	1	(Blitz and Lorenz, 2006)
Singer Moye	1.995	177	16	Town	1000	1100–1450	350	375	1	(Blitz and Lorenz, 2006)
Tukabatchee	2.101	161	20	Town	500	1400–1837	437	0	2	(Knight, 1985)
Upatoi	2.054	252	21	Village	30	1790–1825	35	0	1	(Elliott et al., 1999, Elliott et al., 1996)
Wakokai	1.902	115	12	town	300	1733–1796	63	34	1	(Foster, 2003)

Table 1 continued

	Shannon- Wiener	Sample Size	N Species	Site Type	Population	Date Range	Occupied	Succession	# towns	Reference
Archaic Woodland 1	0.58344	187	11	village	100	2500– 300BC	2200	1530	1	(Benson, 1991, Elliott et al., 1995)
Archaic Woodland 2	1.693	143	23	Village	100	1000BC– 800	1800	1000	1	(Benson, 1991, Elliott et al., 1995)
Archaic Woodland 3	1.679	196	13	Village	100	1000BC– 800	1800	1000	1	(Carruth, 2008, Roemer, 1993, Schnell, 1970)
Archaic Woodland 4	0.939	148	11	Village	100	1000BC– 800	1800	1000	1	(Benson, 1996)
Archaic Woodland 5	0.911	145	14	Village	100	2000BC– 1 AD	2000	1800	1	(Benson, 1992)

by catchment. The average number of trees per catchment was 189. The minimum number of trees in a catchment was 102, and the maximum number of trees in a catchment was 405. The number of species in the 25 catchments averaged 17.16, with a minimum of 11 and a maximum of 26 tree species. Catchments were occupied for a range of years. The shortest occupation was 35 years, and the longest was 2,200 years. Thirteen catchments had undergone zero years of succession at the time that the witness- tree data were collected in the early nineteenth century. The longest length of succession was 1,800 years.

Shannon-Wiener indices range from 0.583 at the oldest site (Archaic Woodland 1), which was occupied between 2500 and 300 B.C., to 2.375 at the Muklassa Hoithlewaulee catchment, which was occupied by a number of communities between approximately 1400 and 1814. The average Shannon-Wiener index for all 25 catchments was 1.661. When the Shannon-Wiener index of diversity was regressed against population, length of occupation, and time of succession, only succession was a statistically significant predictor ($p = .047$). Shannon-Wiener is strongly and negatively correlated with succession (-0.625) and is statistically significant ($p = .001$). Length of occupation is not as statistically significant ($p = .092$) and is positively correlated with diversity. Figure 2 shows an exponential regression model with the Shannon-Wiener diversity index regressed against the number of years of succession at each of the 25 sample sites ($df = 23$, $r^2 = .410$, $p = .001$). It shows the negative relationship between biodiversity and years since abandonment by humans.

The fact that the catchments spanned three physiographic regions may create a bias in the results here. It is likely that the effects of humans on the diversity of forests of the Piedmont were less than their effects on the diversity of forests in the Coastal Plain, where pine dominates. In fact, the authors of a related study (Black et al. 2002; Foster et al. 2004) did not find a significant difference in the Piedmont in the effect of agricultural practices when they compared a forest catchment where Native Americans had lived to a randomly placed catchment where there was known to be no human activity, but they did find a significant difference when they looked at catchments in the Coastal Plain. If we look only at the Coastal Plain catchments as a chronosequence, we can see that succession is still highly negatively correlated with diversity with a Pearson correlation of -0.616 ($n = 19$, $p = .005$).

The fact that these catchments span 3,000 years may also create unknown bias in this study. Dramatic events such as climate change may differentially alter these catchments. The Little Ice age from the sixteenth to nineteenth century may have affected succession; however, the majority of these sites were abandoned toward the end of that era. Palynological investigations in the study region may indicate a gradual warming and drying period during the past

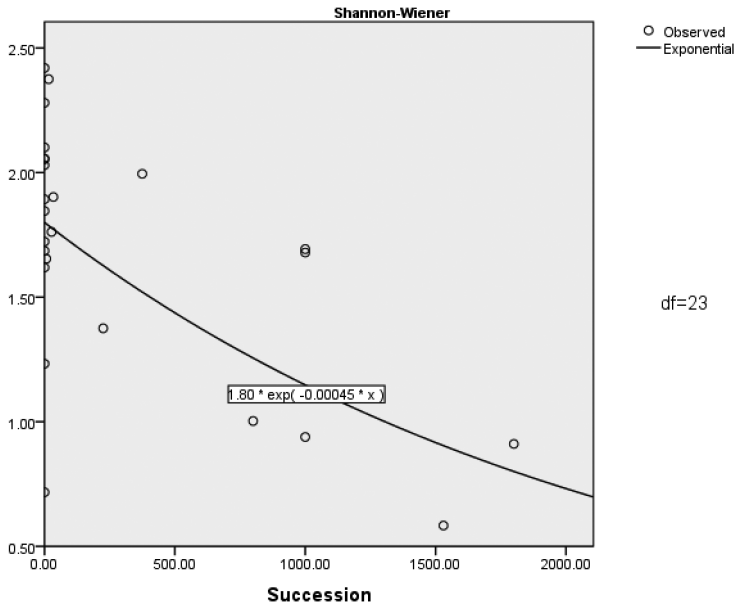


FIGURE 2: *Exponential regression of biodiversity as measured by the Shannon-Wiener metric against years of succession ($r^2=.410$, $p=.001$).*

thousand years (Foster and Cohen 2007). No other dramatic changes are known for the region.

These results indicate that biodiversity in temperate forests decreases as length of time since abandonment increases and that the longer that humans occupied the catchment areas the greater the biodiversity. These two findings complement each other and reveal that Native Americans increased biodiversity near their villages in the southeastern United States over the past 3,000 years. When humans had not lived in an area for a number of centuries, the biodiversity in the catchment decreased. This may be a feature of the temperate forests or the dominance of the pine in the Coastal Plain, since biodiversity loss has been well documented for a number of years in tropical forests (Stahl 1994; Oliveira et al. 2007). The number of species and the evenness of those species are affected in tropical forests, particularly in areas cleared for agriculture.

Human activities such as horticulture increased species diversity in the forests by clearing and encouraging secondary growth. In the pine-dominated forests of the southeastern United States, Native Americans encouraged the growth of nut- and fruit-producing species near their villages. They increased the frequency of economically productive trees at the expense of pine. As soon

as humans abandoned the area, the forests began developing into a nonanthropogenic landscape that eventually contained less biodiversity in the forest composition. They likely increased the diversity of animal species by creating edge environments conducive to herbivores and rodents (Dean 2005). Surveys of historical documents indicate that Native Americans produced a mosaic landscape (Fritz 2000). This study supports those conclusions. Biodiversity is altered in the use area catchments near villages and gardens as a result of horticulture and fire. Overhunting can create resource sinks, however. Overhunting of deer around villages likely had an effect on more recently occupied sites in terms of understory growth (Laurance 2010; McGraw and Furedi 2005).

The Native American method of horticulture increased biodiversity of trees species in localized areas. Native Americans did not cut down large numbers of trees and increased diversity in those areas. They were selective in girdling trees for gardens. There is some indirect evidence that trees were removed in significant amounts in localized regions, however (Foster et al. 2004; Lopinot and Woods 1993). The use of fire to clear gardens resulted in a higher frequency of fire-tolerant species and edge habitats for faunal species (Dean 2005; Foster et al. 2004). This fragmentation of forest, however, has been demonstrated to increase burning (Gascon et al. 2000; Laurance 2010).

Studies of habitat fragmentation have revealed significant effects on ecosystems that are the result of human activity and are likely the result of Native American horticulture and landscape management (Fritz 2000; Hammett 2000). These horticultural economies resulted in nonrandom habitat conversion and localized fragmentation. Fragmentation has less of an effect on biodiversity (Fahrig 2003) but creates edge effects that have an impact on forest structure, soil chemistry, and microclimate. Edge effects such as elevated tree mortality, reduced canopy height, elevated litter fall, soil moisture content changes, and higher understory foliage density, among other effects, occur as far as 400 meters from the edge of the habitat disturbance (Laurance 2010). In very dense Native American settlements such as Cahokia and Copan, these effects were likely long lasting and may have led to economic recession and a degradation of quality of life in those regions. Since these Native American economies did not result in large-scale habitat loss, the documented detrimental effects of gardens on tree biodiversity (Laurance 2010; Fahrig 2003) were reduced. It is likely that there were losses of leaf-litter invertebrate abundance and richness, an abundance of disturbance trees and plants, and a reduction in the number of bird species. Effects on the soil were likely common. Edge effects of habitat loss on soils include changes in phosphorus, soil moisture, and ^{13}C in understory leaves (Laurance 2010).

Understanding resilience of ecosystems and their response to management tactics is crucial to our ability to preserve biodiversity. The United Nations

Convention on Biological Diversity notes that understanding “thresholds” or “tipping points” of ecosystems is crucial to our management of biodiversity loss (Leadley et al. 2010). These thresholds are the result of complex interactions between human activity and the physical environment over long time periods. This essay has shown how we can begin to measure the variability and effect of human interaction with forest ecosystems. The fact that humans alter the forest diversity is not news and has been demonstrated by many sources, but a quantitative understanding of the long-term effects can be obtained only from historical sciences.

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